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(54) Title: METHOD FOR DELIVERING BENEFICIAL COMPOSITIONS TO HAIR FOLLICLES

(57) Abstract

The present invention describes a method for targeted and specific delivery of beneficial compounds, including hair dyes, melanin, proteins, and nucleic acids for gene therapy, to hair follicle cells using liposomes encapsulating the beneficial compound. Particularly preferred methods describe delivery of hair dyes, melanin or tyrosinase to the hair follicle for the purpose of improving hair color or condition, either by encapsulating the compound in liposomes, or by encapsulating a nucleic acid capable of expressing the protein in liposomes. Also described are liposome compositions for practising the methods.

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METHOD FOR DELIVERING BENEFICIAL COMPOSITIONS TO HAIR FOLLICLES

Technical Field of the Invention

This invention relates to methods for specifically delivering therapeutic or other beneficial compounds to hair follicles to improve hair growing from the follicles.

Background of the Invention

There has been a long-felt need for methods of directly influencing hair growth, color and appearance, especially for treatment of alopecia in humans.

Surgical transplantation of small, discrete, skin areas having viable follicles to areas having inactive follicles is expensive, labor-intensive and relatively short-lasting. Also, as described by R.F. Oliver et al. in U.S. Patent 4,919,664, follicular dermal cells can be inserted into a skin incision, resulting in hair growth along the incision. However, this is a complex technique that does nothing to stimulate existing follicles.

Treatment of the hair and skin with various creams or lotions with biologically active ingredients to improve hair growth and other conditions has generally low efficiency. A wide variety of externally applied agents are available for application to the hair to improve body, flexibility, curl, etc. are available. These have limited and only short term usefulness. Coloring hair with various dyes requires frequent repetitions and is not always natural in appearance.

The use of biologically active compounds that are hair growth stimulators or advantageously change other hair characteristics, such as color, would seem to be a more natural and attractive approach, especially at the stage where hair-follicle cells still exist but hair growth, for unknown reasons, is adversely affected. Attempts to follow

this approach have been ineffective, possibly because of the inability of stimulators to penetrate the cellular membrane of hair follicle cells and to enter into the cells where their action is needed.

In the treatment of skin with various absorbable lotions and the like it has long been known that absorption is generally greater in skin areas of higher follicular density. See, for example, Maigach et al, Arch. Environ. Health, 23:208-211 (1971). The absorbed materials, however, were entirely different from liposomes. It was not appreciated prior to the present invention that liposomes could be used to direct beneficial compositions preferentially to hair follicles.

Liposomes, which are artificial phospholipid vesicles, have been successfully used for delivery of different low-molecular-weight water-soluble and oil-soluble compounds into different cells. See, for example, G. Gregoriadis, Trends in Biotechnology, 3:235-241 (1985) and K.H. Schmidt, ed., Liposomes as drug carriers, Stuttgart: George Thieme Verlag (1986).

Liposomes are typically formed by mixing dry phospholipids with aqueous solutions giving rise to bilayers of phospholipid molecules which arrange themselves spontaneously to form close multilayered spherules. As they form, the liposomes entrap liquid and any soluble solutes that are present. A large number of substances that do not interfere with the formation of the liposomes can be incorporated, regardless of solubility, electrical charge, size and other structural characteristics. These characteristics may, however, have adverse affects in some environments limiting the use of liposomes.

Liposomes containing antibody molecules attached for specific targeting have been described for delivery of encapsulated material to targeted cells containing an antigen immunoreactive with the attached antibody, and are

referred to as immunoliposomes. See, for example, U.S. Patent Nos. 4,755,388, 4,925,661 and 4,957,735 for descriptions of immunoliposomes. In addition, liposome compositions have been described that contain protein which are administered to mammalian skin and shown to penetrate in skin keratinocytes. See, U.S. Patent No. 5,190,762. Furthermore, DNA-liposome compositions have also been described, but were not shown to selectively deliver the nucleic acid contents to hair follicles through topical administration. See, U.S. Patent Nos. 5,077,211 and 5,223,263, and Hoffman et al., FEBS Letts., 93:365-368 (1978).

Although various targeting mechanisms have been attempted to increase the specificity of delivery via liposomes, delivery of the encapsulated material into a targeted cell or tissue may not necessarily follow.

Specific tissue delivery is particularly important where the agent being delivered may have a deleterious effect to tissues adjacent to the targeted tissue of interest upon administration of the agent. For example, the agent may produce effects which are acceptable in the hair follicle, but not desired in the adjacent skin tissue. For example, delivery of melanin is desirable for hair pigmentation, but not for general skin pigmentation, and therefore general delivery to all surface skin cells is undesirable, requiring follicle cell specificity. Similarly, gene replacement therapy for expressing melanin or tyrosinase is undesirable in skin cells, but is a desirable result for hair pigmentation.

Transdermal drug delivery provides additional problems where the drug being delivered is destined for the circulation rather than cells of the dermis. Methods for transdermal drug delivery which minimize adsorption into cells of the skin and simultaneously increase transport to the circulation are desirable in certain instances.

However, in instances where delivery is directed solely to the hair follicle, it is desirable that there is minimum adsorption into the skin and minimum transport of the compound into the systemic circulation where the administered compound can exert undesirable side effects.

A small molecule dye, carboxyfluorescein has been found to be delivered to the pilosebaceous units of hamster ear membrane when incorporated in a particular liposomal formulation, as described in a very recent paper by Lieb et al, The Journal of Investigative Dermatology, 99:108-113 (1992). Similarly, Li et al., In Vitro Cell. Dev. Biol., 28A:679-681 (1992), has recently described liposome-mediated delivery of the small molecule dye calcein to hair follicles in an in vitro intact skin histoculture system.

The prior research, however, does not describe methods of specifically and selectively (preferentially) targeting hair follicles using liposomes containing large molecule agents such as proteins or nucleic acids, lipophobic agents that cannot transfer across lipid barriers or lipophillic agents which are capable of undesirable side effects on tissues other that hair follicles.

Furthermore, there have not been any descriptions of methods for accurately testing in vitro the extent to which particular compounds are delivered to hair follicle cells, the effectiveness of the compounds delivered, or liposome formulations for optimizing selectivity of targetting to hair follicles.

Thus, there is a continuing need for improved methods of selectively delivering specific beneficial compounds to hair follicles, and for measuring effectiveness of the delivery.

Summary of the Invention

It has now been discovered that liposomes can selectively target the hair follicle with potentially

beneficial compounds.

Basically, this invention describes methods for preparing liposomes, incorporating beneficial compounds into the liposomes either during formation of the liposomes or thereafter, and applying the liposomes to the skin areas requiring treatment in patients requiring such beneficial treatment. According to the present methods, liposomes preferentially deliver the beneficial compounds to the hair follicles where the compounds enter into the follicle cells. By virtue of the selectivity of the liposome-mediated delivery method, the administered compounds are not delivered substantially to the dermis or internally to the circulation, thereby minimizing undesirable side effects that the administered compound might exert on such dermis tissue or systemically in the circulation.

Typically, the present methods are practiced on the skin of a mammal requiring treatment according to the present methods, such as a human. Thus, the methods can be practiced in vivo.

In order to determine the effectiveness of the hair follicle-specific treatment method of the present invention, an in vitro method of testing particular liposome agents has been developed, utilizing novel histoculturing techniques.

As mentioned above, it is known that a number of compounds, typically dyes and the like, when applied to the skin are more rapidly absorbed in heavily follicularized areas. However, many macromolecular or lipophobic substances cannot cross the plasma membrane or other lipid barriers into the follicle and follicle cells. It has been discovered that when incorporated into liposomes, those macromolecular compounds are successfully transported into the follicle cells, and furthermore can be selectively transferred across the stratum corneum into the follicle without entry to the circulation or the adjacent skin tissue, which has great potential efficacy as well as safety

advantages.

Thus, the invention describes in one embodiment a liposome composition comprising a liposome containing an effective amount of a beneficial compound. The liposome utilized in the liposome composition is capable of selectively delivering the beneficial compound to hair follicles as described further herein. The beneficial compound to be adiministered can be a macromolecule or lipophobic molecule that is not capable of passage through the stratum corneum or cell membrane and requires the liposome-mediated delivery system to selectively and preferentially enter the hair follicle, or is a lipophillic molecule having undesirable effects on cells external to the hair follicles, and requires the selectivity of the liposome-mediated delivery system to preferentially deliver the lipophillic molecule to the hair follicle.

The liposome composition can be utilized for a variety of applications, as described herein, and therefore may contain any of a variety of beneficial compounds, including hair color-restoring agents such as melanin, hair dye, tyrosinase, or a nucleic acid is capable of expressing human tyrosinase, hair growth simulating or hair fortifying agents, agents which inhibit sensitivity to chemotherapeutics, and the like beneficial compounds.

A liposome composition can comprise any of a variety of liposomes designed to selectively target hair follicles, including pH-sensitive liposomes, liposomes comprising a phospholipid selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol, liposomes further comprising a cationic phospholipid selected from the group consisting of D282, D378, D383, D3886, D3897 and D3899, and the like formulations.

The invention also describes a method for restoring hair color to the hair of a mammal, comprising applying a therapeutically effective amount of a liposome composition

to a skin area on said mammal having a plurality of hair follicles, where the liposome composition of the present invention comprises a liposome containing an effective amount of at least one selected hair color-restoring agent. Preferred hair color-restoring agents include melanin, hair dye, tyrosinase, and a nucleic acid capable of expressing human tyrosinase in hair follicle cells.

The invention further describes a method of directly and selectively delivering a beneficial compound to hair follicles of a mammal comprising the step of applying a liposome composition of this invention topically to skin areas of a mammal having a plurality of hair follicles, wherein the liposome composition comprises a liposome containing an effective amount of at least one selected beneficial compound and wherein the beneficial compound is a macromolecule, a lipophobic molecule or a lipophillic molecule having undesirable effects on cells external to said hair follicles. In preferred embodiments, the beneficial compound is a hair color-restoring agent such as melanin, hair dye, or tyrosinase. In related embodiments, the beneficial compound is a hair growth stimulators such as cyclosporin-A or related compounds. In another related embodiment, the beneficial compound is a nucleic acid capable of expressing an effective amount of a replacement therapy protein. Particularly preferred are nucleic acid molecules capable of expressing tyrosinase or hair-growth stimulating proteins or the multi-drug resistance proteins conferring resistance to chemotherapy-induced alopecia.

In other embodiments, the invention contemplates the use of the present liposome compositions according to the present methods for inhibiting chemotherapy-induced alopecia. The liposome compositions contain compounds which reduce in the hair follicle the toxicity of the chemotherapy treatment.

Brief Description of the Drawings

Details of the invention, and of certain preferred embodiments thereof, will be further understood upon reference to the drawing, wherein:

Figure 1A is a fluorescent microscopy image (magnification 500X) of a skin histoculture treated with liposomes containing calcein as described in Example 1 showing highly preferential dye delivery into hair follicles;

Figure 1B is a fluorescent microscopy image (magnification 500X) of a skin histoculture treated with calcein without liposomes as described in Example 1, showing weak dye staining and no preferential delivery to skin structures;

Figure 2 is a hematoxylin and eosin stained paraffin-section of white-haired mouse skin treated with melanin entrapped liposomes for 12 hours, (magnification 500X) as described in Example 2, showing that the liposome-entrapped melanin primarily delivered the melanin to hair follicles as indicated by the arrows;

Figure 3 is a light microscopy image (magnification 250X) of a paraffin section of skin histoculture as in Figure 2 stained with hematoxylin and eosin as described in Example 2, showing delivery of melanin into the hair shaft itself as indicated by the arrows; and

Figure 4 is a histological autoradiogram of histocultured skin treated with liposomes entrapped with radioactive labeled high-molecular weight DNA showing the localization of DNA (arrows) in hair follicle cell membrane and cytoplasm, as described in Example 3.

Figures 5A-5D contain light microscopy images (magnification 125X, Figures 5A and 5C; magnification 250X, Figures 5B and 5D) of sections of skin histoculture prepared as described in Example 4b, in which Figures 5A and 5B illustrate results using liposome-entrapped plasmid (pM-

MuLV-SV-Lac-Z) capable of expressing Lac-Z, and Figures 5C and 5D illustrate results using naked plasmid. The arrows indicate uniform distributions of blue (dark) spots in the hair follicles and shafts indicating active gene transfer to the hair follicles;

Figures 6A-6C contain fluorescent light microscopy images (magnification 150X) of sections of mouse skin samples prepared by treatment of mouse skin in vivo as described in Example 5, in which Figures 6A and 6B illustrate results using liposome-entrapped calcein and Figure 6C illustrates results using naked calcein. The arrows indicate fluorescence in the hair shafts indicating active transfer of calcein to the hair follicles; and

Figures 7A-7C contain light microscopy images (magnification 500X) of sections of mouse skin samples prepared by treatment of mouse skin in vivo as described in Example 5, in which Figures 7A-7C illustrate results using liposome-entrapped melanin.

Figures 8A-8F shows the chemical structure of the cationic phospholipids D282, D378, D383, D3886, D3897 and D3899, respectively.

Detailed Description of the Invention

A. Liposome-Mediated Targeted Delivery of Macromolecules and Nucleic Acids to Hair Follicles

The invention relates to the administration of active compositions directly and selectively (specifically) to the cells of the hair follicle and to the hair shaft itself.

Because of the hair follicle specificity for delivery according to the present invention, the present invention provides the advantage of specifically delivering beneficial compositions to the hair follicle rather than generally to the dermis or circulation, thereby allowing the use of lower amounts of the composition to achieve the desired effect,

and thereby reducing the likelihood of undesirable effects caused by the composition on the skin generally of to the general circulation.

1. Skin Histoculture Assay

In order to demonstrate that liposomes encapsulating beneficial compound are effective at selective delivery, and to provide a means for optimizing liposome mediated delivery formulations, an in vitro assay has been developed. Basically, pieces of skin containing hair follicles are histocultured on collagen-gel-supported sponges as described by Li et al, Proc. Natl. Acad. Sci. USA, 88:1908-1912 (1991); Li et al, Proc. Natl. Acad. Sci. USA, 89:8764-8768 (1992); Li et al., In Vitro Cell. Dev. Biol., 28A:479-481 (1992); Li et al., In Vitro Cell. Dev. Biol., 28A:679-681 (1992); Li et al., In Vitro Cell. Dev. Biol., 28A:695-698 (1992); Li et al., In Vitro Cell. Dev. Biol., 29A:192-194 (1993); and Li et al., In Vitro Cell. Dev. Biol., 29A:449-450 (1993), the teachings of which are hereby incorporated by reference. The system allows the growth of hair shafts in the follicle cells for periods of at least 10-16 days, and further allows the ability to evaluate the three-dimensional appearance of the hair follicle and surrounding tissue by the use of selective dyes and stains in confocal microscopy, thereby providing a system for evaluating the effectiveness of the therapeutic reagent being applied. The use of the three-dimensional histoculture in conjunction with confocal microscopy allows the ability to follow the fine details of candidate beneficial (therapeutic) product-delivering liposome interactions with hair-follicles at the cellular and subcellular level. Therefore, the histoculture system allows the ability to optimize liposome compositions as well as determine the optimum conditions for delivery of the liposome contents into the target cell.

Typical skin histoculture preparation methods are also detailed in copending U.S. Patent Application of Li et al., Serial No. 07/662,239, filed February 28, 1992, and assigned to the assignee of this application, the teachings of which are hereby incorporated by reference.

Native-state histoculturing of a skin sample having hair follicles and internal and external surfaces comprises placing the skin sample on an extracellular support matrix immersed in a medium whereby the internal surface is adjacent to the matrix and the external surface is exposed in the air above the surface of the medium and maintaining the matrix with the skin thereon under skin culturing conditions.

Potentially any skin from any animal can be used in this assay. Preferably, the animal is a mammal. Exemplary mammals are mice, rats, guinea pigs, hamsters, rabbits, marmosets, monkeys and humans. More preferably, the animal is a human.

The skin sample having dermal and epidermal layers is typically excised from an animal. Excess fat, if present, is removed. The sample of skin may be excised from a hairy animal whose skin is capable of supporting hair growth or from a hairless animal whose skin is devoid of hair, such as an athymic, nude animal. Where the skin sample is obtained from a hairy animal, the skin may be shaved or clipped prior to excision.

The skin sample is defined herein as having internal and external surfaces. The phrase "internal surface" refers to the dermally-oriented surface; i.e. the non-exposed surface of the skin as it exists in its native-state in the animal. The phrase "external surface" refers to the epidermally-oriented surface: i.e. the exposed surface of the skin as it exists in its native-state in the animal.

There is no real limitation as to the surface area of a piece of skin used in the present invention. Typically, the

skin sample can range in external surface area from about 1 to about 10,000 square millimeters (mm^2). A preferred surface area is from about 4 to about 100 mm^2. A more preferred surface area is about 10 mm^2. The thickness of the skin is a function of the animal from which it is obtained. Where the skin sample is excised from a mouse, a preferred thickness is about 1 to 2 mm.

Skin samples are cultured on a support matrix. A support matrix of this invention provides a trabecular structure with interstices suited for capillary action to deliver aqueous nutrients from the medium to the internal surface (base) the skin as in a native state. Thus, any support having this capacity is contemplated including synthetic meshes such as nylon, borosilicate glass fiber, or polypropylene or organic meshes such as cellulose or collagen. Preferably, the support matrix is an extracellular support matrix. As used herein, the phrase "extracellular support matrix" means a solid, such as a gel or sponge, comprising one or more organic molecules or molecular aggregates, which molecules or aggregates are those produced and secreted by cells into the extracellular space and which serve, in vivo, as a support, adhesive and framework for maintaining three-dimensional tissue organization and function. Exemplary of such molecules are high-molecular weight proteins and glycoproteins such as collagen, laminin, fibronectin and the like, complex polysaccharides and the like molecules.

In a preferred embodiment, the extracellular support matrix is a collagen-containing gel. Exemplary collagen-containing gels are gelatinized pork skin such as GELFOAM™ (The Upjohn Company, Kalamazoo, MI) and a composition comprising laminin, collagen, proteoglycan and entactin such as MATRIGEL™ (Collaborative Research, Inc., Bedford, MA). GELFOAM™ is a patented product described in U.S. Patent No. 2,465,357, the disclosure of which is incorporated herein by

reference.

In another preferred embodiment, the extracellular support matrix is a homopolysaccharide sponge. Leighton, J., J. Nat'l Cancer Instit., 12: 545-561 (1951). A preferred homopolysaccharide is cellulose. Homopolysaccharide sponges contemplated by the present invention are not limited as to weave or net size.

In still another preferred embodiment, the extracellular support matrix comprises a combination of a collagen-containing gel and a homopolysaccharide sponge. Preferably, such a combination comprises a top layer of a collagen-containing gel and a bottom layer of a homopolysaccharide sponge. The collagen-containing gel is preferably gelatinized pork skin and the homopolysaccharide is preferably cellulose. In a particularly preferred embodiment, the support matrix comprises a combination of a top layer of GELFOAM™ and a bottom layer of a cellulose sponge, which matrix has been shown to be most effective in maintaining normal hair growth of histocultured skin.

There are no set ratios of skin sample size to size of the extracellular support matrix. The matrix can be anywhere from a diameter which is sufficient to support the skin sample to being greater in size and substantially overlapping the skin sample. Multiple samples can be placed on the same matrix so long as the skin samples are not actually touching. A preferred distance between skin samples is about 1 to 2 mm.

The skin sample is placed on the matrix such that the internal surface of the skin is adjacent to the matrix and the external surface of the skin is facing away from the matrix. In a preferred embodiment, the internal surface of the skin is in contact with the matrix. In this arrangement, the external surface of the skin is available for contacting with toxins or other compositions to assess their effect on the skin according to the present methods.

The matrix with the skin sample thereon is immersed in a volume of a medium sufficient to contact the matrix but not to completely cover the skin; i.e. the external surface of the skin is not submerged but is exposed above the surface of the medium. Preferably, the surface of the medium is within 0.5 to 2 mm of the upper surface of the matrix and provides aqueous contact to the skin sample through a wicking effect. For example, where the skin sample has a thickness of about 1 to 2 mm, the surface of the medium is preferably from about 0.5 to about 2 millimeters below the external surface of the skin.

The extracellular support matrix is typically soft and may indent upon placement of the skin sample thereon such that the edges of the matrix may contact the vertical edges of the skin sample.

The extracellular support matrix is pre-treated to equilibrate the matrix with the medium before the skin sample is placed thereon. Pretreatment of the matrix comprises cutting the matrix to a predetermined size and soaking the cut matrix in the medium in a sterile container for a period of time sufficient to saturate and equilibrate the matrix with the medium. A preferred soaking time is 4 hours at 37°C.

The medium contemplated by the present invention is an aqueous nutrient medium designed to promote and maintain viability of the skin sample. A preferred medium is Eagles Minimum Essential Medium (MEM) supplemented with 10% (v/v) fetal bovine serum (FBS) and an antibiotic. Exemplary antibiotics are gentamicin, streptomycin, penicillin, kanomycin and the like. A preferred antibiotic is gentamicin. The final concentration of antibiotic in the medium depends upon the particular antibiotic used. Where the antibiotic is gentamicin, a preferred concentration is about 0.2 mgs per ml of medium. Other media can also be used, preferably involving the use of fetal bovine serum, or

using serum-free defined mediums as is well known in the art.

The matrix with the skin sample thereon may be maintained in the medium for indefinite periods of time. Preferably, the medium is changed every 2 to 3 days.

After a suitable histoculturing period, a quantity of liposomes containing the selected beneficial macromolecular compound is applied to the skin histoculture. A second histocultured skin sample is treated with the compound alone as a control. The skin histocultures are then processed and prepared to asses the viability of the tissues in the skin cell undergoing the treatment, and to determine the specificity of delivery of the beneficial compound in the liposomes.

In one embodiment, viability and/or delivery is assessed by measuring the incorporation into cells of the skin sample of an indicator specific for viable cells. As used herein, the phrase "specific for viable cells" means that the indicator is taken up or incorporated into living, but not dead, cells.

The indicator specific for viable cells may be a metabolic precursor or a non-metabolite that gains access to living cells. Exemplary metabolic precursors are ribo- or deoxyribonucleic acid precursors such as purines, pyrimidines, nucleosides and nucleotides. Preferably, the metabolic precursor is operatively linked to an indicating means to facilitate detection. A preferred indicating means for a metabolic-precursor indicator is a radiolabel such as ^{35}S, ^{32}P, ^{125}I, ^{3}H and the like. A particularly preferred radiolabeled metabolic-precursor indicator is ^{3}H-thymidine.

A preferred non-metabolite indicator specific for viable cells is a dye that is capable of optical detection. Any dye recognized in the art as being specific for viable cells can be used in accordance with the skin toxicity assay of this invention. See, e.g., Handbook of Fluorescent

Probes and Research Chemicals, ed. by R.P. Haugland, Molecular Probes, publisher, Eugene, Oregon (1989-1991 and 1992-1993).

In a preferred embodiment, the dye is a fluorescent dye. Exemplary viable-cell-specific fluorescent dyes are BCECF-AM (B-1150), Calcein-AM (C-1430), CFDA (carboxyfluorescein diacetate; C-195) Acridine orange (A-1301), Calcein blue (H-1426), Fura-2AM (F-1201), Fluorescein diacetate (F-1303) or Carboxy analog (C-1431) and the like. Such dyes are well known in the art and are commercially available (Molecular Probes, Eugene OR). Particularly preferred are the dyes BCECF-AM or Calcein-AM. The numerals in the parenthesis indicates the product number for the listed fluorescent dyes that are available from Molecular Probes.

In one embodiment, the incorporation or uptake of fluorescent dyes specific for viable cells depends upon metabolic activity of the viable cell. In accordance with this embodiment, non-fluorescing dyes are taken up by viable cells and converted to a fluorescing product by an intracellular enzyme such as an esterase. The presence of intracellular fluorescence indicates viability.

In another embodiment, viability is assessed by measuring the uptake or incorporation into cells of the skin sample of an indicator specific for dead cells. As used herein, the phrase "specific for dead cells" means that the indicator is taken up or incorporated only into dead, non-viable cells.

Typically, dyes specific for dead cells are compounds with a high ionic charge and low permeability such that the dyes cannot permeate intact cellular membranes. When cells die, the membrane is structurally or functionally ruptured such that dyes specific for dead cells gain access to the intracellular space where they bind to intracellular components such as nuclear membranes.

A preferred dead-cell-specific indicator is a dye capable of optical detection. A preferred dead-cell-specific dye is a fluorescent dye such as propidium iodide, ethidium bromide, ethidium homodimer [(5,5'-diazadecamethylene) bis (3,8-diamino-6-phenyl-phenanthridium) dichloride, dihydrochloride] and the like. most preferred is propidium iodide. Propidium iodide (PI) and other dyes specific for dead cells are well known in the art and commercially available (Molecular Probes, Eugene, OR).

In still another preferred embodiment, assessing viability is accomplished by simultaneously measuring the uptake or incorporation of both an indicator specific for viable cells and an indicator specific for dead cells. Viability is assessed as the ratio of viable to dead cells. Where both the indicator specific for viable cells and the indicator specific for dead cells are fluorescent dyes, such dyes should have different emission spectra so as to facilitate discrimination between viable and dead cells. Compositions and methods for determining cell viability by the differential uptake of indicators specific for viable and dead cells and tissue culture samples are well known in the art. Haugland, Supra.

Means for detecting the uptake or incorporation of indicators specific for viable cells are dependent upon the particular indicator used and are well known to those of skill in the art. A preferred means for detecting radiolabeled metabolic-precursors is autoradiography of histological sections of the skin samples that have taken up the precursor.

A preferred means for detecting dyes is microscopic examination. Microscopic examination can involve the use of any microscope that allows one to selectively and reproducible evaluate indicator incorporation into specific cells of the skin sample at varying locations within the

three-dimensional, native-state skin histoculture.

Typically, the microscopic examination requires the capability of optical sectioning. Optical sectioning is the ability to view preselected depths within the three-dimensional structure of the skin in the absence of optical interference provided by the presence in the skin of microsomes, air bubbles, fat globules and other tissue components, which provide reflection of light and optical interference.

In addition, optical sectioning allows for viewing a variety of planes within the three-dimensional skin histoculture. By sequentially sectioning serial layers of the skin, one can produce a total picture of the skin and hair follicle or, alternatively, a picture of a region of the skin and the follicles where a particular cell type of interest is located. Thus, comparative studies of a plurality of depths or regions of the skin can be made. In this way, viability can be assessed in surface cells, at cells underneath the dermal layer, cells inside the epidermal layer, or in other specific cell types such as nerve cells, oil secreting cells, hair follicle cells.

The optical section thickness can be varied to accommodate the cell size or tissue to be observed and can range from about 0.1 to 1000 microns. Preferred sections are in the range of 0.5 to 10 microns, preferably about 2 to 6 microns.

A preferred microscope that is capable of performing optical sectioning is a confocal scanning laser microscope such as the MRC-600 CONFOCAL IMAGING SYSTEM (Bio-Rad, Richmond, Ca.), mounted on a Nikon Optiphot using a 10x PlanApo plan objective. Such a confocal scanning microscope has been successfully used to asses delivery (see the Examples). Other available methods for optically scanning or sectioning planes of the tissue sample are also contemplated by the present invention.

Viability is assessed at any particular location within the skin as a ratio of viable or dead cells to total cells or as a ratio of live to dead cells on the basis of the uptake of indicators specific for viable and dead cells respectively. When viability is assessed both before and after contact with a putative beneficial compound, comparing the ratio of live to dead cells as assessed before and after contact with the putative beneficial agent provides an indication of the toxicity or benefit provided by the administered compound.

The procedure for applying indicators to the skin culture varies with the particular indicator used. Typically, indicators are added to the medium about 6 hours and, preferably about 24 hours after placing the skin sample in the medium. Following addition of the indicator to the medium, the culture is maintained under culturing conditions for a period time sufficient to allow the indicator to enter and label the cells of the skin sample. Preferably, the culture is maintained in the presence of the indicator for about 5 minutes to about 2 hours and, more preferably for about 10 to 20 minutes.

The concentration of indicator added to the medium varies with the particular indicator used. Where the fluorescent dyes PI and BCECF-AM are used, the dye concentration is from about 1 to about 100 micromolar, preferably from about 2 to about 50 micromolar, and more preferably about 5 micromolar each.

Exemplary in vitro skin histoculture methods are described in the Examples.

Results of studies herein on liposome-mediated delivery show that the beneficial macromolecular compound is concentrated at the hair follicles and has been transported across the cell membrane and through the cytoplasm to the nucleus. The liposome-incorporated material (beneficial compound) is preferentially delivered to the hair follicle,

because the levels of the beneficial compound in the adjacent skin tissue is substantially lower than in the hair follicles. Due to the unusual selectivity of delivery to the hair follicle when using the disclosed liposome formulations, and based on the degree of selectivity based on the compound to be delivered and the liposome formulation utilized, this selectivity is referred herein to as "directed delivery", "preferential delivery", "selective delivery" and in some cases as "exclusive delivery", depending upon the relative amount of material delivered to the hair follicle tissue as compared to the adjacent skin tissue. In addition, the selectivity can be expressed in terms of the selectivity of pharmaceutical effect upon the hair follicle tissue as compared to the adjacent skin tissue.

With the tissue sample treated with the macromolecular compound where the compound had not been incorporated in liposomes, very little reaches the follicle cell or follicle cell nuclei. Thus, the liposome-based system specifically, selectively, and efficiently targets the hair follicles with compounds that otherwise do not concentrate at the hair follicles.

The in vitro histoculture assay can be utilized in a variety of ways. The assay can be utilized to evaluate and optimize liposome formulations for enhanced efficacy of delivery of the beneficial compound, or to study other aspects of the liposomes usefulness in the targeting formulation. Furthermore, the assay can be used as a screening system to identify additional beneficial compounds for treating conditions afflicting hair follicles as described further herein.

In addition, the in vitro histoculture assay methods can be utilized to determine the effective dosages of beneficial compounds for use in the present methods.

2. Preparation of Liposomes Encapsulating Beneficial Compounds, and Liposome Compositions

A beneficial liposome composition of the invention is typically provided in one or more of a variety of compositional forms suitable for the contemplated use. Although proteins, nucleic acids or other compounds for use in a liposome generally retain biological activity in a variety of buffers and solutions, it is preferred to be formulated in a phospholipid composition. Particularly preferred are phospholipid compositions which afford maximum stability and biological activity of the beneficial compound in the composition. Such phospholipid compositions are preferably formulated to form liposome compositions, as are generally well known in the art. Typically, the composition contains an amount of biologically active beneficial compound suitable for its contemplated use.

The preparation of liposomes, and their use in drug therapy has been previously described. See, for example, U.S. Patent Nos. 4,241,046, 4,394,448, 4,529,561, 4,755,388, 4,828,837, 4,925,661, 4,954,345, 4,957,735, 5,043,164, 5,064,655, 5,077,211 and 5,264,618, the disclosures of which are hereby incorporated by reference. Exemplary methods for the entrapment of nucleic acids into liposomes is described in U.S. Patent No. 5,223,263.

Preferred and exemplary methods for preparing beneficial compound-encapsulated liposomes for use in the present methods are described in the Examples. In particular, the encapsulation of melanin, protein or nucleic acid, each for delivery to hair follicles as a beneficial compound, are described herein.

The liposome compositions of the present invention typically comprise about 0.1 mg to about 3 mg of protein, or about 0.1 ug to about 0.5 mg nucleic acid, per mg of phospholipid mixture.

The ratio of active compound to phospholipid mixture may determine the sensitivity of the resulting reagent. Thus, use of a ratio of about 1 to 2 mg protein per mg phospholipid mixture may be suitable for a protein reagent having a International Sensitivity Index ("ISI") of about 1.0. Use of a ratio of about 0.25 to about 0.5 mg protein per mg phospholipid mixture may be suitable to prepare a composition having an ISI of about 1.6 to about 2.0.

Preferred are compositions that additionally comprise from about 0.5 to about 1.5% (w/v) glycine. Where it is desired to be able to lyophilize the liposome composition to allow storage and later reconstitution, the reagent preferably includes a cryopreservative, preferably a carbohydrate preservative, most preferably trehalose.

The lipid bilayer of the liposomes comprises phospholipids, preferably, phosphoglycerides. Exemplary liposome compositions include phosphatidylcholine (PC) liposomes, particularly egg PC (EPC) and dipalmitoyl PC (DPPC). Additional candidate liposome compositions are prepared according to the teachings of United States Patent No. 4,394,488, the teachings of which are incorporated by reference, particularly the descriptions of liposomes comprising phosphotidylethanolamine (PE), phosphotidylserine (PS), sphingolipids, phosphotidylglycerol (PG), phosphatidic acid (PA), cholesterol, spingomyelin cardiolipin, various cationicphospholipids glycolipids, gangliosides, cerebrosides and the like, used either singularly or in combination.

"Phospholipid" refers to an organic molecule derived from either glycerol (most commonly) or sphingosine. Phospholipids derived from glycerol (or phosphoglycerides) comprise a glycerol backbone, two fatty acid chains esterified to the first and second carbons of the glycerol and phosphoric acid esterified to the third carbon. Optionally, an alcohol moiety is esterified to the

phosphoric acid.

Suitable phospholipids for use in the liposome compositions of the present invention include those which contain fatty acids having twelve to twenty carbon atoms; said fatty acids may be either saturated or unsaturated. The phospholipids may come from any natural source and the phospholipids, as such, may be comprised of molecules with differing fatty acids. Phospholipid mixtures comprising phospholipids from different sources may be used. For example, PC, PG and PE may be obtained from egg yolk; PS may be obtained from animal brain or spinal chord. These phospholipids may come from synthetic sources as well.

Phospholipid (PL) mixtures having a varied ratio of individual PLs may be used. However, although the phospholipids may be used in varied ratios, mixtures of phospholipids having preselected amounts of individual phospholipids result in liposome compositions having advantageous activity and stability of activity. Thus although a wide range of ratios of individual phospholipids may be used, for advantageous activity and stability of the resulting liposome composition, certain phospholipid compositions are preferred.

The phospholipids are conveniently combined in the appropriate ratios to provide the PL mixture for use in preparing the liposome composition of the present invention.

Liposomes are preferably prepared using one or more phospolipids including (N-(1-(2,3-dioleolyoxy)propyl)-N,N,N-trimehtyl ammonium chloride) (DOTMA), dioleoyl-phosphatidylethanolamine (DOPE), dioleoyl-phosphatidylcholine (DOPC), phosphatidylethanolamine (PE), egg PC (EPC), phosphatidylcholine (PC), dipalmitoyl PC (DPPC), cholesterol and the like phospholipids. Phospholipids can be obtained from a variety of sources, including Avanti (Birmingham, AL), GIBCO BRL (Gaithersburg, MD) and Aldrich (Milwaulkee, WI), or can be prepared from

available materials, as is well known.

Preferred liposomes comprise PC, EPC, or DPPC homogeneously. Further preferred liposome compositions comprise a combination of a PC-type phospholipid (such as PC, EPC, DOPC, DPPC and the like) combined with a PE-type phospholipid (PE, DOPE and the like) in a molar ratio of from about 2:5 to about 5:2, more preferably about 5:2 PC:PE. A preferred liposome composition comprises PC:PE:Chol in a molar ratio of 5:2:3.

A preferred liposome for use in the present invention additionally includes cationic phospholipids. One preferred cationic phospholipid is a monocationic phospholipid having two identical alkyl side chains.

Preferred cationic phospholipids are also generally available from a variety of sources, including the above recited sources. Particularly preferred cationic phospholipids include cationic phospholipids such as D282, D378, D383, D3886, D3897 and D3899, obtainable from Molecular Probes (Eugene, OR), the structure and synthesis of which is well known and described in Handbook of Fluorescent Probes and Research Chemicals, ed. by R.P. Haugland, Molecular Probes, publisher, Eugene, Oregon (1989-1991, and 1992-1993). The structures of cationic phospholipids D282, D378, D383, D3886, D3897 and D3899 are shown in Figure 8.

D282 is also known as 1,1'-dioctadecyl-3,3,3',3'-tetramethylindocarbocyanine perchlorate; D378 is also known as 3,3'-diheptyloxacarbocyanine iodide; D383 is also known as 1,1'-didodecyl-3,3,3',3'-tetramethylindocarbocyanine perchlorate; D3886 is also known as 1,1'-dioleyl-3,3,3',3'-tetramethylindocarbocyanine methanesulfonate; D3897 is also known as N-4-(4-dilinoleylaminostyryl)-N-methylpyridinium iodide; and D3899 is also known as 1,1-dilinoleyl-3,3,3',3'-tetramethylindocarbocyanine perchlorate.

In one embodiment, the liposome composition of this

invention contains one or more of the above cationic phospholipids. Preferably, a liposome composition of this invention comprises a formulation of phospholipids comprising a mixture of (a) one or more of the phospholipids PC, EPC, DOPC, DPPC, PE, DOPE, cholesterol and the like phospholipids, and (b) one or more of the cationic phospholipids D282, D378, D383, D3886, D3897, D3899 and the like. A particularly preferred liposome composition comprises a mixture of phospholipid (a) and cationic phospholipid (b) in a ratio of about 0.5 to 2.0 moles of phospholipid (a) to about 0.5 to 1.5 moles of phospholipid (b), and more preferably about 1.0-1.2 moles of phospholipid (a) to 0.8 moles of cationic phospholipid (b). A preferred phospholipid composition in this embodiment comprises a mixture of DOPC or DOPE with one or more of the above cationic phospholipids in a ratio of about 0.8 moles to about 1.0-1.2 moles.

In another embodiment, the invention comprises a liposome composition comprising one or more phospholipids selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol, combined with one or more phospholipids to form pH-sensitive liposomes. pH-sensitive liposomes are generally well known and their preparation has been described by Straubinger et al., FEBS Letts., 179:148-154 (1985). A preferred pH sensitive liposome comprises oleic acid (OA) and PE at a mole ratio of 3:7. OA is available from a variety of commercial sources, including Sigma (St. Louis, MO).

The preferential targetting of a liposome composition of this invention to the hair follicle can be optimized by the choice of phospholipids in the liposome composition, and may depend additionally on the included beneficial compound. Optimization can be readily conducted by use of the in vitro histoculture assay method described herein by preparation and testing of a panel of preselected liposome formulations

according to the phosopholipid parameters described herein.

Particularly preferred parameters for targeting beneficial compounds to hair follicles include the combined use of liposomes that have both cationic lipids and are pH-sensitive.

Where the liposome composition will be lyophilized prior to storage for later use, it is preferred to include a carbohydrate or carbohydrates as cryopreservative(s) to protect the integrity of liposomes in the resulting liposome composition during lyophilization and subsequent rehydration.

Cryopreservation relates to preserving the integrity of delicate substances when liquids containing them are frozen and dehydrated. The use of a carbohydrate as a cryopreservative of liposome integrity upon freezing and subsequent lyophilization has been reported. Racker, E., Membrane Biol., 10: 221-235 (1972); Sreter, F. et al., Biochim. Biophys. Acta., 203: 254-257 (1970); Crowe et al., Biochem. J., 242: 1-10 (1987); Crowe et al., Biochim. Biophys. Acta., 987: 367-384 (1988).

Suitable carbohydrate cryopreservatives include trehalose, maltose, lactose, glucose and mannitol. According to a preferred aspect of the present invention, trehalose is included in aqueous buffer solution used in the preparation of a liposome composition of the present invention (prior to lyophilization), preferably at a concentration in the range of about 50 mM to about 250 mM.

The phospholipids, which may be obtained from the manufacturer in an organic solvent, are mixed together in the appropriate ratios to yield the specified composition. An antioxidant can also be added to reduce alkyl chain peroxidation of the fatty acid portions of the phospholipids, and the organic solvent, if present, is removed by evaporation. One suitable antioxidant is butyrated hydroxy toluene. Preferably about 0.1% (by

weight) of antioxidant is used.

The dried (evaporated) phospholipid mixture is then redissolved with an aqueous detergent solution. Suitable detergents include those which have a relatively high critical micelle concentration (CMC). Womack et al., Biochim. Biophys. Acta, 733: 210 (1983). Such detergents include detergents having a CMC of greater than approximately 2 mM. Preferred are those detergents having a CMC of between approximately 2 to 25 mM. Such preferred detergents include 3-[(3-cholamidopropyl)-dimethylammonio]-1-propanesulfonate (CHAPS) and alkylglucopyranosides such as octyl beta-D-glucopyranoside, octyl beta-D-thioglucopyranoside and the like. Optionally, the detergent solution may include other components. These components may include buffer salts such as HEPES, Tris, phosphate, and the like; various other salts such as NaCl, KCl, and the like; a carbohydrate cryopreservative such as trehalose, maltose, glucose, and the like; and glycine.

According to a preferred embodiment of the present invention, the detergent solution comprises 20 mM Tris, pH 7.5, 150 mM NaCl, (TBS) containing 100 mM CHAPS, 150 mM trehalose and 0.8% glycine. According to this preferred embodiment, the phospholipids are redissolved in this solution to give a final concentration of about 20 mg/ml.

Purified proteins for use in a liposome, together with carrier protein, are combined with the redissolved phospholipids and the volume of the resulting mixture is adjusted with a buffer as described above, preferably containing cryopreservative (most preferably trehalose) and glycine but no detergent. Protein is admixed with carrier protein, such as bovine gamma globulin, and sufficient buffer is added to adjust the final concentrations of active protein to 10 mg/ml, bovine gamma globulin to 1 mg/ml, phospholipid to 4 mg/ml and detergent to 20 mM. Suitable

buffers include TBS containing 150 mM trehalose and 0.8% glycine.

The resulting clear, colorless solution requires no vortexing or sonicating to ensure co-solubilization.

The detergent in the phospholipid admixture can be removed by a number of methods resulting in a stable liposome composition having a protein or nucleic acid associated with and inserted through the lipid bilayer. Suitable methods of removal of detergent include dialysis, tangential flow diafiltration, cross flow hollow fiber filtration, treatment with hydrophobic chromatography resin, and simple dilution.

One preferred method of detergent removal from the phospholipid admixture utilizes dialysis for at least 30 hours at room temperature in dialysis membrane tubing against a buffer such as TBS containing 150 mM trehalose, 0.8% glycine and 0.05% NaN_3 to remove the detergent. Another preferred method of detergent removal utilizes resin treatment. Suitable resins include hydrophobic chromatographic resins such as Amberlite XAD-2 (Rohm and Haas Co. in Philadelphia, Pennsylvania) or Bio-Beads SM-2 (BioRad in Richmond, California). The resins may be used to remove the detergent, either by direct contact with the phospholipid solution admixture or separated from it by a dialysis membrane. The rate of removal of detergent from the phospholipid admixture is proportional to the weight ratio of the detergent in solution and the chromatographic resin beads.

The liposome solution resulting from the detergent removal step is then made to 5 mM $CaCl_2$. According to one preferred aspect, the liposome composition which contains the fully active compound is diluted to a concentration of 50 mM Tris, pH 7.5, 75 mM trehalose, 0.8% glycine and 10 to 15 mM $CaCl_2$ before use. Alternatively, the diluted reagent may be lyophilized for long term preservation of its

biological performance characteristics and then later reconstituted by suspension in water before use.

Another preferred method of detergent removal avoids the use of either dialysis or resin treatment and yet provides for preparation of active reagent. According to this method, detergent solubilized phospholipid compositions containing protein or nucleic acids are diluted into a buffer without detergent to produce mixed micelles containing the beneficial compound which remain capable of being fully activated by $CaCl_2$. According to this aspect of the invention, phospholipids are dissolved to 20 mg/ml in a buffer containing detergent, preferably an alkyl glucopyranoside. A suitable buffer-detergent solution comprises 20 mM HEPES (pH 6) containing 50 mM octyl beta-D-thioglucopyranoside (OTG) and 150 mM NaCl. Carrier protein, active protein or nucleic acid, and $CaCl_2$ are then added and the mixture diluted further with buffer without detergent, such as 20 mM HEPES (pH 6) containing 150 mM NaCl, to yield final concentrations of active protein or nucleic acid at about 10 mg/ml, carrier protein (bovine gamma globulin) at 1 mg/ml, $CaCl_2$ at 5mM, phospholipids at 4 mg/ml, and OTG at 10 mM. The reagent may be lyophilized for storage as described above, or diluted as described above before use.

According to another aspect of the present invention, this reagent may be prepared by following methods for the preparation of vesicles and detergent-phospholipid mixed micelles from phospholipids by methods based on mechanical means, by removal of organic solvents, by detergent removal, and by size transformation as has been described by Lichtenberg, D. and Barenholz, Y., Methods of Biochemical Analysis, 33: 337-462 (1988), and the disclosures of which are incorporated herein by reference.

Incorporation of a beneficial compound is conducted by

incorporation of the compound in the liposome either during liposome formation, or after formation by combining the liposome with the compound. Methods of introducing the compound into the liposome can vary, and are not intended to be limiting. Preferred methods are described in the Examples.

Where nucleic acid is entrapped into a phospholipid composition, a wide variety of ratios of nucleic acid to phospholipid may be utilized as discussed earlier. However, it is preferred to use about 100 micrograms (ug) of nucleic acid (in the form of double-stranded DNA such as plasmid DNA) with about 0.1 to 10.0 milligram (mg) phospholipid. Where cationic phospholipids are to be utilized in a phospholipid composition, it is particularly preferred to use about 100 ug nucleic acid to from 0.2 to 1.2 micromoles (umole) of phospholipid, particularly 100 ug nucleic acid to 0.8 umole.

Preferred liposome compositions of this invention comprise a liposome containing an effective amount of a beneficial compound of this invention. Preferred beneficial compounds depend upon the use of the liposome composition as described further herein, and can include melanin, hair dyes, tyrosinase, nucleic acids, hair color-restoring agents, hair growth-promoting agents, and agents which confer chemorestistance to the targeted hair follicle.

3. Hair Follicle-Targeted Drug Therapy

In one embodiment, the invention describes methods for selective and beneficial targeting of therapeutic compounds and compositions to the hair follicle of a mammal.

Based on the present disclosure, it is determined that compounds and compositions, particularly polymers, dyes, proteins, nucleic acids and macromolecules, are specifically delivered to hair follicle tissue, so long as the compounds

or compositions are encapsulated in liposomes.

The invention contemplates the delivery of a wide variety of beneficial or otherwise therapeutic compounds to the hair follicle, with the selectivity of delivery to the hair follicle over adjacent skin tissue cells being of particular importance, and the primary result according to the present methods. Thus, the therapeutic compounds can be nucleic acids, hormones, proteins, enzymes, vitamins and other biochemical co-factors deemed to provide a therapeutic effect upon the hair follicle cell's growth, condition, color and the like.

Thus, a beneficial compound for use in the methods and compositions of this invention can be any of a variety of molecules including molecules that would not otherwise be able to reach hair follicles, such as macromolecules and polymers that are too large to penetrate stratum corneum or lipid barriers such as cell membranes, and lipophobic molecules that are not able to penetrate lipid barriers due to their chemical properties. Additional beneficial compounds for use in the present invention include lipophillic compounds that do exhibit a capacity to interact with and penetrate lipid barriers, but which can penetrate other tissue barriers such as dermis where the compound can exhibit potentially undesirable effects upon cells external to the hair follicle. Thus, a beneficial compound can be a macromolecule, a polymer, a lipophobic molecule, a lipophillic molecule having undesirable effects on cells external to the hair follicles, and the like compounds.

Particularly preferred are agents (beneficial compounds) which improve the growth of the hair shaft, agents which stimulate the production of hair coloring pigments in the hair follicle, agents which replace pigment in the follicle cell or hair shaft or which color (dye) the hair shaft (i.e., restore hair color), agents which stimulate hair growth, and agents which prevent hair loss.

Agents useful for restoring or pigmenting hair color include melanin or hair dyes, which directly color hair as a pigment, and the protein tyrosinase, which is an enzyme which catalyzes the production of melanin pigment precursors and thereby increases pigment production in hair follicle cells, and nucleic acids which encode and express tyrosinase and other proteins which stimulate hair growth or prevent hair loss.

As is well known, melanin is a polymer of tyrosine that occurs in a variety of forms and polymer lengths. Thus, the use of the term "melanin" is intended to mean melanin in any of its forms which can be utilized in the present invention. Also contemplated for use in this invention are derivatized melanin, extracted melanin, modified melanin, and the like variants of melanin which have the desirable property of providing hair pigment.

Hair dyes are also extremely well known, and can take a wide variety of forms that need not limit the present invention. In particular, it is noted that hair dyes are typically aromatic compounds which are incidentally mutagenic or otherwise exhibit undesirable effects of marious tissues of the body such as cells external to a hair shaft or hair follicle, such as in the dermis or in the circulation. Therefore it is to be emphasized that the present invention provides the advantage by virtue of selective delivery to the hair follicle of reducing the extent of contact of administered hair dye with dermis and other tissues external to the hair follicle.

Agents useful in conditions of hair loss (alopecia) are those which stimulate hair growth, those which inhibit the hair loss, and those which inhibit the conditions that cause hair loss, such chemotherapeutic agents. Hair growth stimulators are generally well known, and include minoxidil, substance-P, cyclosporin and the like known hair growth stimulators.

A preferred embodiment involves the prevention of hair loss (alopecia) during chemotherapy where a patient experiences chemotherapy-induced hair loss due to the effect of the chemotherapeutic agent on the hair follicle and surrounding tissue. Thus the invention contemplates the use of inhibitors of the deleterious effects of a chemotherapeutic agent. By virtue of the selective application of the inhibitor to the hair follicle by the liposome-mediated delivery methods of the present invention, inhibition of a chemotherapeutic agent is localized to the hair follicle and therefore does not interfere with the intended systemic activity of the administered chemotherapeutic agent. In this embodiment, a preferred inhibitor of chemotherapy-induced alopecia is a gene product of the multiple drug resistance (MDR) gene, preferably the p-glycoprotein expressed by the human MDR-1 gene. Administration of a nucleic acid comprising an expression vector capable of expressing human p-glycoprotein via liposomes to the hair follicle provides intracellular human p-glycoprotein, and reduces the toxic effects of the chemotherapy upon the hair follicle, thereby reducing alopecia induced by the chemotherapy.

Another embodiment contemplates the use of the human transformation growth factor-alpha (TGF-α) gene to reverse the "wavy" hair phenotype. See for example, Mann et al., Cell, 73:249-261 (1993), and Luetteke et al., Cell, 73:263-278 (1993). Therefore the invention contemplates the use of a cDNA expression vector that expresses the TGF-α gene as a beneficial compound to reduce the incidence of wavy hair where the deficiency of TGF-α gene is the cause of the wavy hair phenotype.

The invention additionally contemplates the administration of any gene beneficial to hair follicles. A gene is beneficial to hair follicles where it confers, upon selective delivery to the hair follicles by the present

methods, a beneficial effect upon the hair follicle. Exemplary beneficial genes include genes normally and preferentially expressed in hair follicle, and therefore important for normal gene function. Beneficial genes can be identified by any of a variety of molecular biological methods. For example, a cDNA library of expressed genes can be prepared from hair follicle tissue supporting healthy hair, and can be enriched by subtractive hybridization against a cDNA library derived from a non-hair-producing or vellus-hair-producing follicle tissue, thereby producing a library of cDNA molecules whose expression is specific to hair follicles. Individual cDNA molecules from the hair specific cDNA library can be further screened for therapeutic effectiveness using the skin histoculture assay described herein.

Particularly preferred is a gene capable of stimulating hair growth, referred to as a hair growth stimulating gene. A hair growth stimulating gene is any nucleic acid which stimulates hair growth upon administration of the gene to hair follicles of skin according to the present liposome-mediated delivery methods. A hair growth stimulating gene can be prepared from the hair specific cDNA library described above. The hair growth stimulating gene can be selected from the hair specific cDNA library by a variety of methods. The gene can be identified by subtractive hybridization using a cDNA library prepared from skin tissue which has vigorous hair shaft production against a cDNA library prepared from skin tissue which is deficient in vigorous hair shaft production, such as patches of skin where hair is absent or thinning. Such areas of skin have hair follicles but the follicle cells are experiencing changes in gene expression which effect the condition of the hair, particularly the rate of hair shaft growth. The resulting cDNA library following subtractive hybridization against the hair growth deficient cDNA library is further

screened in the in vitro skin histoculture assay for cDNA molecules capable of stimulating hair growth to identify hair growth stimulating genes. Methods for isolating cDNA libraries and for conducting subtractive hybridization a well known in the art, and are not to be considered as limiting to the present invention.

The therapeutic agent can be delivered to the hair follicle in the form of an active formulation, such as the pigmentation protein or enzyme itself, or can be provided through gene replacement therapy, where a nucleic acid is introduced that expresses the protein to be delivered. In this mode, also referred to as gene therapy, a replacement therapy protein is provided which exerts a beneficial effect. The protein is referred to as a "replacement therapy" protein to connote that the therapy administered is to reconstitute (replace) into the tissue a protein-based function not previously present. It does not mean that a gene or protein was first deliberately removed, and then replaced.

Again, some beneficial compounds may have the ability to exhibit undesirable effects on tissues or cells external to the hair follicle, such as the dermis or other tissues accessed by the general circulation. Therefore it is noted that the selectivity provided by the present invention provides the advantage of reducing toxicity or undesirable effects of certain beneficial compounds. This is particularly important for cyclosporins useful as hair growth stimulators but which can suppress the immune system is contacted with the circulation, and for agents which confer chemoresistance in tissues where it is undesirable to provide such resistance such as in the circulation.

A therapeutic amount of a therapeutic protein in a liposome composition of this invention is an amount sufficient to produce the desired result, and can vary widely depending upon the disease condition and the potency

of the therapeutic compound.

Thus, in one embodiment, the invention contemplates a method for directly and selectively delivering a beneficial compound to the hair follicles of a mammal comprising the steps of:

a) incorporating an effective amount of at least one selected beneficial compound into a liposome; and

b) applying said liposomes to skin areas of the mammal having a plurality of hair follicles;

whereby said beneficial compound is preferentially transmitted to said hair follicles and enters into said hair follicles.

In a related embodiment, the invention describes a method of directly and selectively delivering a beneficial compound to hair follicles of a mammal comprising the step of applying a liposome composition of this invention topically to skin areas of a mammal having a plurality of hair follicles. The liposome composition comprises a liposome containing an effective amount of at least one selected beneficial compound wherein the liposome is capable of selectively delivering the beneficial compound to the hair follicles and whereby the beneficial compound is preferentially transmitted to the hair follicles and enters into the hair follicles.

As described, the beneficial compound can be a protein, a nucleic acid or other molecule having desirable properties upon delivery to the hair follicle cell. Where the compound is a a pigment such as melanin or hair dye, or is a protein, such as tyrosinase, the objective is to restore hair color in hair as demonstrated herein. Alternatively, the compound can be aromitase or cyclosporin where the objective is to stimulate hair growth. Alternatively, the compound can be a nucleic acid encoding tyrosinase, aromitase, p-glycoprotein, TGF-α, a hair growth stimulating gene or other beneficial proteins, or can encode and express an antisense

or ribozyme nucleic acid as discussed herein.

Thus, in a related embodiment, the invention contemplates a method for restoring hair color to the hair of a mammal comprising applying a therapeutically effective amount of a liposome composition to a skin area on the mammal populated with hair follicles. The liposome composition contains an effective amount of a beneficial compound capable of restoring hair color (a hair color-restoring agent). The hair color-restoring agent can be any of a variety of hair dyes, the pigment melanin, the protein tyrosinase, or a nucleic acid capable of expressing a tyrosinase cDNA as described herein.

In a related embodiment, the invention contemplates a method for inhibiting chemotherapy-induced alopecia in a mammal undergoing chemotherapy comprising applying a therapeutically effective amount of a liposome composition to a skin area on the mammal populated with hair follicles. The liposome composition contains an effective amount of a beneficial compound capable of inhibiting within the follicle cell environment the toxic effects of the chemotherapy, e.g., a protein that confers chemoresistance to hair follicle cells and hair follicles. Any compound that inhibits chemotherapy toxicity is contemplated, although the MDR-1 gene product (p-glycoprotein) is particularly preferred.

The method can be practiced on a variety of mammals, including agricultural stock such as cow, sheep, horse, goat, pig, and the like, pets such as cats, dogs or other domesticated mammals, and humans. Typically, the hair follicle is present in the skin of a mammal, and the method is practiced <u>in vivo</u> on a living mammal for the purpose of benefitting the condition of the hair follicle or hair shaft of the mammal.

In one embodiment, the selected beneficial compound is a protein which affects hair growth, alopecia, hair color or

hair condition. Preferred are the proteins tyrosinase or aromitase, as well as nucleic acids coding for hair modifying proteins. In a related embodiment, the selected beneficial compound is a pigment, such a melanin.

Melanin, hair dyes and tyrosinase are preferred for their role in coloring hair. Aromitase, minoxidil and cyclosporin-A are preferred for their role in stimulating hair growth. Other therapeutic compounds suitable for use in stimulating hair growth in conditions of alopecia include cyclosporin analogs, substance P, estrogen analogs and anti-androgens. Therapeutic compounds suitable for use in preventing hair growth, such as facial or pubic hair, include alopecia inducers, catagen blockers, epidermal growth factor, and the like inhibitors of hair growth.

In another embodiment, the selected beneficial compound is a nucleic acid capable of expressing a beneficial protein which affects hair growth, alopecia, hair color or hair condition as described earlier. Preferred are the nucleic acids that express the proteins tyrosinase, aromitase, or other hair-growth stimulators, the protein products of the MDR-1 gene (i.e., p-glycoprotein) to prevent chemotherapy-induced alopecia, or enzymes which synthesize those proteins.

In one preferred embodiment, the invention contemplates a method for restoring hair color in mammals, particularly man, in which the hair color is greying for any of a variety of reasons, including age. The method comprises applying a therapeutically effective amount of a liposome composition of this invention to a skin area on the mammal having a plurality of hair follicles which exhibit fading or greying hair color. The liposome composition preferably contains an effective amount of a hair color-restoring agent of this invention, such as a hair dye, melanin, tyrosinase or a nucleic acid capable of expressing human tyrosinase in the cells of the hair follicles. Preferably, the nucleic acid

encodes a human tyrosinase gene including the nucleotide sequence characteristics of the tyrosinase gene sequence shown in SEQ ID NO 1.

In one embodiment, the application of the liposome composition can be repeated at defined intervals to provide prolonged effectiveness, such as prolonged hair color-restoration or prolonged chemoresistance depending on the treatment, as needed.

Insofar as a liposome composition of this invention is used therapeutically, the liposome composition is itself a therapeutic composition, and as such may also contain additional components.

Therapeutic compositions of the present invention contain a physiologically tolerable carrier together with at least one species of liposome composition of this invention as described herein, dispersed therein as an active ingredient. In a preferred embodiment, the therapeutic composition is not immunogenic when administered to a human patient for therapeutic purposes.

As used herein, the terms "pharmaceutically acceptable", "physiologically tolerable" and grammatical variations thereof, as they refer to compositions, carriers, diluents and reagents, are used interchangeably and represent that the materials are capable of administration upon a mammal or human without the production of undesirable physiological effects such as nausea, dizziness, gastric upset and the like.

The preparation of a pharmacological composition that contains active ingredients dispersed therein is well understood in the art. Typically such compositions are prepared as sterile compositions either as liquid solutions or suspensions, aqueous or non-aqueous, however, suspensions in liquid prior to use can also be prepared.

The active ingredient can be mixed with excipients which are pharmaceutically acceptable and compatible with

the active ingredient and in amounts suitable for use in the therapeutic methods described herein. Suitable excipients are, for example, water, saline, dextrose, glycerol, ethanol or the like and combinations thereof. In addition, if desired, the composition can contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents and the like which enhance the effectiveness of the active ingredient.

The therapeutic composition of the present invention can include pharmaceutically acceptable salts of the components therein (e.g., protein, nucleic acid or other compounds). Pharmaceutically acceptable salts include the acid addition salts (formed with the free amino groups of the polypeptide) that are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, tartaric, mandelic and the like. Salts formed with the free carboxyl groups can also be derived from inorganic bases such as, for example, sodium, potassium, ammonium, calcium or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, 2-ethylamino ethanol, histidine, procaine and the like.

Physiologically tolerable carriers are well known in the art. Exemplary of liquid carriers are sterile aqueous solutions that contain no materials in addition to the active ingredients and water, or contain a buffer such as sodium phosphate at physiological pH value, physiological saline or both, such as phosphate-buffered saline. Still further, aqueous carriers can contain more than one buffer salt, as well as salts such as sodium and potassium chlorides, dextrose, propylene glycol, polyethylene glycol and other solutes.

Liquid compositions can also contain liquid phases in addition to and to the exclusion of water. Exemplary of such additional liquid phases are glycerin, vegetable oils such as cottonseed oil, organic esters such as ethyl oleate,

and water-oil emulsions.

A therapeutic composition contains a liposome composition of the present invention, typically an amount of at least 0.1 weight percent of liposome composition per weight of total therapeutic composition. A weight percent is a ratio by weight of liposome composition to total composition. Thus, for example, 0.1 weight percent is 0.1 grams of liposome composition per 100 grams of total composition.

A therapeutically effective amount of a liposome composition, or beneficial compound therein, is a predetermined amount calculated to achieve the desired effect, i.e., to effectively benefit the targeted hair follicle, depending upon the benefit to be conferred. Thus, an effective amount can be measured by improvements in one or more symptoms associated with the condition of the hair follicle or hair follicle shaft occurring in the patient.

Thus, the dosage ranges for the administration of the liposome composition of the invention are those large enough to produce the desired effect in which the condition in the hair follicle to be treated is ameliorated. The dosage should not be so large as to cause adverse side effects. Generally, the dosage will vary with the age, condition, sex and extent of the disease in the patient and can be determined by one of skill in the art.

The dosage can be adjusted by the individual physician in the event of any complication.

The compositions are administered in a manner compatible with the dosage formulation, and in a therapeutically effective amount. The quantity to be administered depends on the subject to be treated, capacity of the subject's system to utilize the active ingredient, and degree of therapeutic effect desired. Precise amounts of active ingredient required to be administered depend on the judgement of the practitioner and are peculiar to each

individual. However, suitable dosage ranges for systemic application are disclosed herein and depend on the conditions of administration. Suitable regimes for administration are also variable, but are typified by an initial administration followed by repeated doses at one or more hour intervals by a subsequent administration.

4. Nucleic Acid Expression Vectors for Gene Therapy

In a particularly preferred embodiment, the invention contemplates the use of recombinant DNA molecules that can function as expression vectors for expressing a beneficial protein via a liposome-mediated targeting method of this invention.

"Recombinant DNA (rDNA) molecule" refers to a DNA molecule produced by operatively linking two DNA segments. Thus, a recombinant DNA molecule is a hybrid DNA molecule comprising at least two nucleotide sequences not normally found together in nature. rDNA's not having a common biological origin, i.e., evolutionarily different, are said to be "heterologous".

In living organisms, the amino acid residue sequence of a protein or polypeptide is directly related via the genetic code to the deoxyribonucleic acid (DNA) sequence of the structural gene that codes for the protein. Thus, a structural gene or DNA segment can be defined in terms of the amino acid residue sequence, i.e., protein or polypeptide, for which it codes.

An important and well known feature of the genetic code is its redundancy. That is, for most of the amino acids used to make proteins, more than one coding nucleotide triplet (codon) can code for or designate a particular amino acid residue. Therefore, a number of different nucleotide sequences may code for a particular amino acid residue sequence. Such nucleotide sequences are considered

functionally equivalent since they can result in the production of the same amino acid residue sequence in all organisms. Occasionally, a methylated variant of a purine or pyrimidine may be incorporated into a given nucleotide sequence. However, such methylations do not affect the coding relationship in any way.

The DNA segments for use in the present invention are characterized as including a DNA sequence that encodes a beneficial protein as described herein. Particularly preferred segments encode tyrosinase, aromitase, other hair-growth stimulating proteins, melanin, p-glycoprotein, TGF-α, or enzymes that synthesize those proteins. That is, the DNA segments of the present invention are characterized by the presence of a structural gene encoding one or more of the recited beneficial proteins. Preferably the gene is present as an uninterrupted linear series of codons where each codon codes for an amino acid residue found in the beneficial protein, i.e., a gene free of introns.

One preferred embodiment is a DNA segment that codes an amino acid residue sequence that defines a tyrosinase protein corresponding in sequence to a wild type tyrosinase protein and the DNA segment is capable of expressing tyrosinase. A preferred DNA segment codes for an amino acid residue sequence consisting essentially of the tyrosinase encoding nucleic acid sequence. Human tyrosinase gene and its nucleotide sequence is well known including the cDNA sequence for expressing human tyrosinase, and has been described by Tamate et al., J. Exp. Zool., 250:304-311, (1980); Shibahara et al., J. Exp. Med., 156:403-414 (1989); Takeda et al., Biochem. Biophys. Res. Comm., 162:984-990 (1989); Bouchard et al., J. Exp. Med., 169:2029-2042 (1989); and Brichard, J. Exp. Med., 178:489-495 (1993).

Insofar as there is redundancy in the genetic code, it is understood that a variety of nucleotide sequences may be utilized to express a particular amino acid residue

sequence. Therefore, in one embodiment, the invention contemplates the use of a nucleotide sequence that encodes a human tyrosinase protein, preferably having the amino acid residue sequence characteristics of the amino acid residue sequence shown in SEQ ID NO 1. A particularly preferred nucleotide sequence for expressing human tyrosinase according to the present invention has the nucleotide sequence characteristics of the nucleotide sequence shown in SEQ ID NO 1.

For expression of the human tyrosinase gene, any of a variety of expression vectors may be utilized so long as the vector is compatible with expression in mammalian cells, particularly human cells. Suitable vectors are well known. A preferred vector is the pRHOHT2 vector described in the Examples, although other mammalian expression vectors are suitable.

Another preferred embodiment is a DNA segment that codes an amino acid residue sequence that defines a multiple drug resistance (MDR) gene product, preferably the MDR-1 gene product designated p-glycoprotein, corresponding in sequence to a wild type p-glycoprotein and the DNA segment is capable of expressing p-glycoprotein. A preferred DNA segment codes for an amino acid residue sequence consisting essentially of the p-glycoprotein encoding nucleic acid sequence. Human p-glycoprotein, the MDR-1 gene and the MDR-1 nucleotide sequence are well known including the cDNA sequence for expressing human p-glycoprotein, and has been described by Chen et a., Cell, 47:381-389 (1986); Ueda et al., J. Biol. Chem., 262:505-508 (1987); and Kioka et al., Biochem. Biophys. Res. Comm., 162:224-231 (1989).

Insofar as there is redundancy in the genetic code, it is understood that the invention contemplates the use of a nucleotide sequence that encodes a human p-glycoprotein, preferably having the amino acid residue sequence characteristics of the amino acid residue sequence shown in

SEQ ID NO 2. A particularly preferred nucleotide sequence for expressing human p-glycoprotein according to the present invention has the nucleotide sequence characteristics of the nucleotide sequence shown in SEQ ID NO 2.

Another preferred embodiment is a DNA segment that codes an amino acid residue sequence that defines a transforming growth factor-alpha (TGF-α) protein corresponding in sequence to a wild type TGF-α protein and the DNA segment is capable of expressing tyrosinase. A preferred DNA segment codes for an amino acid residue sequence consisting essentially of the TGF-α encoding nucleic acid sequence. Human TGF-α gene and its nucleotide sequence is well known including the cDNA sequence for expressing human TGF-α, and has been described by Jakowlew et al, Mol. Endocrinol., 2:1056-1063 (1988).

Insofar as there is redundancy in the genetic code, it is understood that the invention contemplates the use of a nucleotide sequence that encodes a human TGF-α protein, preferably having the amino acid residue sequence characteristics of the amino acid residue sequence shown in SEQ ID NO 3. A particularly preferred nucleotide sequence for expressing human TGF-α according to the present invention has the nucleotide sequence characteristics of the nucleotide sequence shown in SEQ ID NO 3.

Homologous DNA and RNA sequences that encode the above beneficial proteins are also contemplated.

In another embodiment, the invention contemplates the delivery of antisense or ribozyme nucleic acids to hair follicle cells for the purpose of selectively inhibiting hair follicle gene expression, and control aspects of hair follicle cell function.

Antisense nucleic acids are generally well known in the art and function to hybridize with sense strands of messenger RNA (mRNA), thereby interfering with the normal expression of the hybridized mRNA molecule. The sequence of

the antisense nucleic acid depends, as is well known, upon the nucleotide sequence of the mRNA to be hybridized. See for example, Stein et al., Science, 261:1004-1012)1993).

Ribozyme nucleic acids are also generally well known in the art as single-stranded (ss) RNA molecules that are capable of selectively cleaving ssRNA and ssDNA. The ribozyme is useful to selectively inhibit gene expression by cleavage of a target ssRNA or ssDNA molecule in a hair follicle cell.

Representative targets for antisense or ribozyme nucleic acids are deleterious genes in hair follicle cells, such as the genes responsible for baldness, hair loss, loss of hair color, strength or condition, and the like undesirable features of hair follicles and hair shafts. In a preferred embodiment, the invention contemplates liposome-mediated delivery of an antisense or ribozyme nucleic acid capable of inhibiting expression of the gene that produces androgen receptor, thereby inhibiting follicle cell production of the receptor, thereby reducing hair loss.

The preparation and use of antisense or ribozyme nucleic acids is well known in the art, and the design of particular antisense or ribozyme nucleic acids are not themselves considered to be part of the present invention. However, insofar as the invention contemplates methods for liposome-mediated delivery of antisense or ribozyme nucleic acids to hair follicles for the purpose of improving delivery and selectivity of the effect exerted by the delivered nucleic acid, the present invention is not to be limited to any particular species thereof but rather describes general methods of their delivery as a beneficial compound.

DNA segments (i.e., synthetic oligonucleotides) used to produce a larger DNA segment that encodes a beneficial protein can easily be synthesized by chemical techniques, for example, the phosphotriester method of Matteucci, et

al., (J. Am. Chem. Soc., 103:3185-3191, 1981) or using automated synthesis methods. In addition, larger DNA segments can readily be prepared from smaller DNa segments by well known methods, such as synthesis of a group of oligonucleotides that define the DNA segment, followed by hybridization and ligation of oligonucleotides to build the complete segment.

Furthermore, DNA segments consisting essentially of structural genes encoding a beneficial protein can be obtained from recombinant DNA molecules containing a gene that defines the beneficial protein isolated from natural sources. Exemplary natural sources are described in the references cited herein where the cDNA sequences are described.

In addition, the invention contemplates the use of a recombinant DNA molecule (rDNA) containing a DNA segment of this invention. A rDNA can be produced by operatively linking a vector to a DNA segment of the present invention.

As used herein, the term "vector" refers to a DNA molecule capable of autonomous replication in a cell and to which another DNA segment can be operatively linked so as to bring about replication of the attached segment. A vector capable of directing the expression of a gene that encodes a beneficial protein is referred to herein as an "expression vector". Thus, a recombinant DNA molecule is a hybrid DNA molecule comprising at least two nucleotide sequences not normally found together in nature.

The choice of vector to which a DNA segment of the present invention is operatively linked depends directly, as is well known in the art, on the functional properties desired, e.g., protein expression, and the host cell to be transformed, these being limitations inherent in the art of constructing recombinant DNA molecules. However, a vector contemplated by the present invention is at least capable of directing the replication, and preferably also expression,

of the beneficial protein structural gene included in DNA segments to which it is operatively linked.

In preferred embodiments, a vector contemplated by the present invention includes a procaryotic replicon, i.e., a DNA sequence having the ability to direct autonomous replication and maintenance of the recombinant DNA molecule extrachromosomally in a procaryotic host cell, such as a bacterial host cell, transformed therewith. Such replicons are well known in the art. In addition, those embodiments that include a procaryotic replicon also include a gene whose expression confers drug resistance to a bacterial host transformed therewith. Typical bacterial drug resistance genes are those that confer resistance to ampicillin or tetracycline.

Those vectors that include a procaryotic replicon can also include a procaryotic promoter capable of directing the expression (transcription and translation) of the beneficial protein gene in a bacterial host cell, such as E. coli, transformed therewith. A promoter is an expression control element formed by a DNA sequence that permits binding of RNA polymerase and transcription to occur. Promoter sequences compatible with bacterial hosts are typically provided in plasmid vectors containing convenient restriction sites for insertion of a DNA segment of the present invention. Typical of such vector plasmid are pUC8, pUC9, pBR322 and pBR329 available from Biorad Laboratories, (Richmond, CA) and pPL and pKK223 available from Pharmacia, Piscataway, N.J.

Expression vectors compatible with eucaryotic cells, preferably those compatible with mammalian cells, and particularly hair follicle cells, can also be used to form the recombinant DNA molecules for use in the present invention. Mammalian cell expression vectors are well known in the art and are available from several commercial sources. Typically, such vectors are provided containing

convenient restriction sites for insertion of the desired DNA segment, and provide the signals required for gene expression in a mammalian cell. Typical of such vectors are the pREP series vectors and pEBVhis available from Invitrogen (San Diego, CA), the vectors pTDT1 (ATCC #31255), pCP1 (ATCC #37351) and pJ4W (ATCC #37720) available from the American Type Culture Collection (ATCC) and the like mammalian expression vectors.

Particularly preferred are mammalian expression vectors which allow the expression of the gene in a tissue-specific manner, in this case by the action of a regulatory promotor that will limit gene expression to hair follicle cells.

Successfully transformed hair follicle cells, i.e., follicle cells that contain a rDNA molecule of the present invention, can be identified by well known techniques. For example, cells resulting from the introduction of an rDNA of the present invention can be subjected to assays for detecting the presence of specific rDNA using a nucleic acid hybridization method such as that described by Southern, J. Mol. Biol., 98:503 (1975) or Berent et al., Biotech., 3:208 (1985).

In addition to directly assaying for the presence of rDNA, successful transformation can be confirmed by well known immunological methods for the presence of expressed protein. For example, follicle cells successfully transformed with an expression vector produce proteins displaying beneficial protein, which then can be assayed directly by immunological methods.

Alternatively, successful transformation of the target tissue can be confirmed by evaluation of the target tissue for indicia of function exerted by the administered beneficial compound. For example, where the compound is a nucleic acid expressing tyrosinase, as described in the Examples, the exerted function of pigmentation, or the presence of tyrosinase activity or enzymatic conversion of

L-dopa to product can be detected directly in the target tissue.

B. Methods for Identifying Genes That Encode Proteins Beneficial to Hair Follicles

In another embodiment, the invention provides a method for identifying a gene that encodes a protein that can exhibit a beneficial effect upon a hair follicle. The method comprises the steps of (1) encapsulating a nucleic acid molecule containing the gene of interest into a liposome composition of this invention, (2) contacting the nucleic acid-containing (encapsulated) liposome with a skin sample histoculture as described herein and having at least one hair follicle, thereby delivering the nucleic acid to the follicle, and (3) observing whether the delivered nucleic acid, upon expression of any protein encoded thereon, exhibits a beneficial effect on the hair follicle. The effect observed can be changes in hair color, condition, growth rate, viability, condition of the associated hair follicle cell structures, and the like indicia of cellular response.

In one embodiment, the present method is well suited to screening gene libraries for the presence of a gene capable of expressing a protein that exhibits a beneficial effect on a hair follicle. Gene libraries can be in the form of cDNA libraries or genomic DNA libraries as is well known. The beneficial effect to be induced depends on the screening method to detect the effect, as described further herein.

The following Examples serve to illustrate particular embodiments of the invention and are not limiting of the specification and claims in any way. The examples detail the application and testing of liposome-based treatments hair follicles and hair growth problems. Parts and percentages are by weight unless otherwise indicated.

Examples

1. Liposome-Mediated Delivery of Dye to Hair Follicles

Liposome-mediated delivery of beneficial agents to hair follicles is demonstrated using a native-state skin sample histoculturing method in which hair follicle-containing skin samples are cultured allowing the growth of the hair follicle, and detailed observation of the hair follicle cells during the treatment with therapeutic liposomes.

For the histoculture of skin, pieces of shaved outbred white-haired-mouse or nude-mouse skin, approximately 2 x 5 x 2 mm, were harvested under a dissection microscope and then histocultured on collagen-gel supported sponge as described by Li et al., Proc. Natl. Acad. Sci. USA, 88:1908-1912, (1991). Histoculture was continued for about 24 hours prior to contacting the skin histoculture with the liposome preparation.

Liposomes were prepared by sonication of about 15 mg phosphatidylcholine (PC) emulsion in phosphate buffered saline (PBS) containing about 20 mg/ml of the fluorescent dye calcein. Liposomes were also prepared by entrapping NBD-phosphatidylcholine fluorescent dye using an emulsion with about 20 mg/ml of the NBD formulation. Liposomes were separated from the non-entrapped dye by gel-filtration on a Sepharose 4B column diluted with phosphate buffered saline. The amount of entrapped dye was measured spectrofluorometrically. Two types of PC were used: egg PC (EPC) and dipalmitoyl PC (DPPC). Due to their phase transition temperatures, liposomes made of DPPC are in a gel phase at about 37°C while liposomes prepared from EPC are in a liquid-crystalline state.

Samples of the mouse skin histocultures were incubated for about 20 minutes with each of the liposomes and with a

solution of "free" calcein dye at the same concentrations used in the liposome preparation. After the tissue samples were thoroughly washed with culture medium free of liposomes to remove excess liposome composition, the specimens were analyzed with a BioRad MRC 600 laser confocal microscope with a BHS filter block, which excites the tissue at 488 nm and passes the light emitted at 520 nm. These parameters are close to the excitation and emission maxima reported for calcein, Haugland,(Ed.) Molecular probes. Handbook of Fluorescent Probes and Research Chemicals, Molecular Probes, Inc., Eugene, (1989-1991 and 1992-1993). There is no autofluorescence of tissue when these emission and excitation wavelengths are used. The MRC-600 Confocal Imaging System (Bio-Rad, Richmond, CA) was mounted on a Nikon Optiphot equipped with a 10X PlanApo Objective.

Figure 1A shows the skin histoculture incubated with calcein-entrapped EPC liposomes. Note the high efficiency of the delivery of the fluorescent dye preferentially into hair follicles. Figure 1B shows the skin histoculture incubated with free calcein solution. Note the relatively low fluorescence with no preferential staining of any particular skin structure. The image in Figure 1B was made with the same parameters of aperture and gain control as Figure 1A.

To study the differences in liposome-mediated delivery depending upon the type of liposome used, additional liposomes were prepared as above except using DPPC in the liposome. The results obtained using either calcein or NBD-phosphatidylethanolamine as the fluorescent label showed selective labelling of the hair follicle at the surface of the follicle rather than inside the follicles when EPC was used. Thus, different liposome compositions allow even greater selectivity in delivery to a preselected region of the follicle.

The above results show a difference between

substantially preferential staining of hair follicles obtained with dye entrained in DPPC or EPC liposomes compared to a lack of preferential staining of follicles over skin with free dye. Thus, liposome-entrapped dye, in contrast to free dye, becomes specifically associated with hair follicles, indicating that liposomes specifically target hair follicles.

2. Liposome-Mediated Delivery of Melanin to Hair Follicles

The targeted delivery of a beneficial compound to hair follicles was demonstrated using melanin as the model because melanin provides the benefit of pigmentation.

To that end, liposomes were prepared by sonication. About 20 mg of egg phosphatidycholine was rotary evaporated with a vacuum drier from a chloroform solution to form a thin film on the walls of a 5 ml round-bottomed flask for about 1 hour. The dried thin film phospholipid was suspended in about 0.5 ml phosphate buffered saline (pH 7.4) on a vortex mixer and then sonicated with a Branson probe-type sonicator fitted with a microtip at power level 3 for about 8 minutes. Then 0.5 ml of a solution of melanin (10 mg/ml) was entrapped with the above suspension by sonication for about an additional 4 minutes. Liposomes were separated from the non-entrapped melanin by gel-filtration on a Sepharose 4B column equilibrated with phosphate buffered saline.

Pieces of outbred white-haired mouse skin derived from 1-2 weeks-old animals (about 2 x 5 x 2 mm each) were harvested under a dissection microscope. The samples were then histocultured on collagen-gel supported sponges as described in Example 1. Liposome interaction with the skin was initiated after about 24 hours of histoculture. Mouse skin histocultures were incubated for about 12 hours with liposomes. As a control, a solution of "free" melanin at

the same concentration as was used in the liposome preparation was also incubated for about 12 hours with pieces of the histocultured skin.

The skin histocultures were counter-stained with the dye 2',7'-bis(2-carboxyethyl)-5 which is activated to fluorescence by nonspecific esterases present only in living cells. After the tissues were thoroughly washed, the specimens were analyzed with a Nikon fluorescence microscope equipped with a fluorescein cube. Microscopically the live tissues and cells fluoresced green such that dark dense melanin deposits localized in the tissue can be clearly identified against the green background. All skin samples were then fixed with formalin and processed through dehydration, paraffinization, paraffin-embedding and hematoxylin and eoxin (H&E) staining.

Figure 2 shows the liposome-mediated targeted delivery of melanin to the hair follicles in the skin histocultures stained with H&E. In the paraffin section of white-haired mouse skin treated for 12 hours with the melanin-entrapped liposomes, the majority of the melanin can be seen to be localized around the hair follicles. The melanin can be seen at the periphery of follicles and in the follicle cells themselves. Figure 3 shows a side view of a H&E-stained hair follicles, showing that the liposome-entrapped melanin was delivered into the hair shaft itself to form the band-like melanin-distribution pattern in the terminally-differentiated keratinocytes of the typical normal pigmented hair shaft. Note that the liposome-delivered melanin seen in Figure 3 exhibits a natural pattern in the hair shaft mimicking a natural melanized hair shaft. In the control (not shown), in which the skin histocultures had been incubated with the "free" melanin, no "free" melanin can be observed either in hair shafts or the hair follicular cells.

Thus, liposomes can specifically target an important, large, polymer to hair follicles and even enter into the

hair shaft itself in a normal pattern.

3. Liposome-Mediated Delivery of Nucleic Acid to Hair Follicles

a. Delivery of Nucleic Acids to a Cultured Cell Line

The targeted delivery of nucleic acid to hair follicles was demonstrated using mouse genomic DNA cleaved to about 1 kilobase (kb) lengths as the model for nucleic acids capable of expressing protein due to the typical size of a DNA expression vector, and the size of a typical structural gene.

About 1 kb DNA was isolated from a mouse genomic DNA library and purified from low melting point agarose with the Magic DNA Purification Kit (Promega, Madison, WI). About 50 ng DNA was labeled with [^{35}S]dATP (DuPont) with the Random Primer DNA Labeling Kit (BioRad, Richmond, CA). The specific activity of the labeled DNA with ^{35}S-dATP was 2.6 x 10^{10} cpm/μg.

Liposomes were prepared by freezing and thawing. About 20 mg of egg phosphatidylcholine (EPC) was rotary evaporated with a vacuum drier from a chloroform solution to form a thin film on the walls of a 5 ml round-bottomed flask for about 1 hour. The dried film phospholipid was suspended in an about 0.5 ml phosphate buffered saline solution at a pH of about 7.4 in a vortex mixer and then sonicated with a Branson probe-type sonicator fitted with a microtip at power level 3 for about 8 minutes. The 0.5 ml of [^{35}S]dATP-labeled DNA solution was added to the above suspension by extensive vortexing for about 1 minute and followed by freezing and thawing. Liposomes were separated from the non-entrapped [^{35}S]dATP by gel-filtration on a Sepharose 4B column equilibrated with PBS. About 50 μl calcein (about 10 mg/ml) was added into the solution in order to mark the liposomes during the separation. The specific activity of

the entrapped DNA labeled [^{35}S]dATP was 2.5 x 10^{10} cpm/μl measured by liquid scintillation counting.

Pieces of outbred white-haired-mouse skin (about 1 x 5 x 2 mm) derived from 1-5 week-old animals were harvested under a dissection microscope and then histocultured on collagen-gel-supported sponges as described in Example 1. Liposome interaction with the skin was initiated after about 24 hours of histoculture. Mouse skin histocultures were then incubated for about 44 hours with liposomes. As a control, a solution of naked-[^{35}S]DNA at the same concentration was used in the liposome preparation and was also incubated with skin histocultures.

The skin histocultures were washed with phosphate-buffered saline, pH 7.0, placed in histology capsules and fixed in 10% (v/v) formalin. The fixed skin cultures were then dehydrated, embedded in paraffin, sectioned and placed on slides by standard methods well known to those of skill in the histology art. The slides were deparaffinized, coated with Kodak NTB-2 emulsion, exposed for 5 days and developed. See, e.g. Freeman et al., Proc. Soc. Natl. Acad. Sci. USA, 83:2694-2698 (1986) Hoffman et al., Proc. Soc. Acad. Sci. USA, 86:2013-2017 (1989); and Li et al., Proc. Soc. Acad. Sci. USA, 88:1908-1912 (1991). The developed slides were rinsed, stained with hematoxylin and eosin and examined using a Nikon or Olympus photomicroscope fitted with epi-illumination polarization.

The histological autoradiogram of Figure 4 shows [^{35}S]DNA-labeled hair and follicle cells in the histocultured skin after the skin was incubated with the DNA liposomes for about 44 hours. High radioactive labeling by the [^{35}S]DNA in the cell membranes and cell cytoplasm as well as in the cell nucleus can be seen in Figure 4, as pointed out by the arrows. This shows that the liposomes have delivered the DNA across the cell membrane and the DNA is transported through the cytoplasm to the nucleus.

When the histocultured skin was treated with naked-[^{35}S]DNA there were only a few radioactive labelled cells. For further comparison, the percent of labeled follicles per 20X field and percent of labeled cells per follicle in the areas of maximum labeling can be calculated from the autoradiogram of Figure 4. The percent of labeled follicles per 20X field is found to be about 7 times higher for the liposome carried labeled DNA compared to the naked labeled DNA, and the percent of labeled cells per follicle is at least 4 times higher for the liposome carried labeled DNA compared to the naked labeled DNA.

This Example demonstrates that liposomes can specifically and efficiently target DNA into the hair follicles, and therefore establish that liposome encapsulated nucleic acids are useful reagents for targeting gene therapy to hair growth processes.

b. Delivery of Liposome-Entrapped Nucleic Acid Expressing the Human Tyrosinase Gene to a Cultured Cell Line

Cloned human tyrosinase gene was transferred to tissue cultured cell lines using liposomes to demonstrate the efficiency of liposome-mediated delivery and expression of a tyrosinase gene.

To that end, liposomes were prepared by well known freezing and thawing methods. About 20 mg of phospholipid in a ratio of 5:3:2 of phosphatidylcholine (PC): cholesterol (Chol): phosphatidylethanolamine (PE) was rotary evaporated with a vacuum drier from a chloroform solution for 1 hour to form a thin film on the walls of a 5 ml round-bottomed flask for about 1 hour. The dried film phospholipid was suspended in 2 ml phosphate buffered saline solution at a pH of about 7.4 (PBS) in a vortex mixer and then sonicated with a Branson probe-type sonicator fitted with a microtip at power level 3 for about 8 minutes. Then 200 ug of the plasmid

pRHOHT2 was entrapped in a liposome by addition of the plasmid to the sonicated suspension, sonication of the admixture in a water bath for 2 minutes, followed by freezing and thawing three times to form nucleic acid-containing liposome composition.

Plasmid pRHOHT2 was obtained from Dr. S. Shibahara and is described by Shibahara et al., J. Biol. Chem., 262:12889-12892 (1987), and Takeda et al., Biochem. Biophys. Res. Comm., 162:984-990 (1989), and contains a full length human tyrosinase cDNA, including promoters for expression of tyrosinase in mammalian cells.

Human fibroblast FS-3 and mouse amelanotic K1735 cell lines were each pre-cultured in 60 mm culture dishes with Eagle's MEM medium containing 10% fetal bovine serum (FBS) and Dulbecco's Modified Eagle's medium containing 10 FBS, respectively, for 24 hours. Thereafter, the cultured cells were contacted with 0.5 ml of the tyrosinase gene-entrapped liposome composition in 1.5 ml of the respective culture medium per culture dish, and the contacted cells were maintained for 48 hours under culturing conditions. Thereafter, the cells were further cultured for 7 days (FS-3) or 3 days (K1735) with normal culture medium after aspiration of the liposome-containing medium.
The cells were then harvested by trypsin digestion and centrifuged at 800 x g for 5 minutes to attach the cells to cytospin slides. As a control, 50 micrograms (ug) of naked plasmid in 0.5 ml medium was added to the two cell types in place of the 0.5 ml liposome preparation.

The expression of tyrosinase was evaluated by measuring dopa-oxidase reactions and immunhistochemical staining for tyrosinase in the treated cells.

To detect dopa oxidase activity, the cytospin slides were incubated with 1 mg/ml of L-dopa in PBS for 12 hours at 37 degrees C as described by Kugelman et al., J. Invest. Dermatol., 37:73-76 (1961). Thereafter, the cytospin slides

were counterstained with hematoxylin and eosin by established procedures, and the dopa oxidase-positive cells were identified and counted using a microscope.

To detect tyrosinase immunohistochemically, a Dako LSAB (labeled streptavidin-biotin) kit was used to stain tyrosinase-containing cells. The cytospin slides were fixed in acetone for 10 minutes, and then air-dried. Thereafter, serial incubations were then performed for 10 min each sequentially in hydrogen peroxide, blocking serum, a dilution (1:400) of primary antibody (anti-tyrosinase), linking antibody, peroxidase-conjugated streptavidin, and 3-amino-9-ehtylcarbazol substrate solution as described by the manufacturer of the kit (Dako, Carpinteria, CA). The primary antibody was rat anti-human tyrosinase monoclonal antibody TMH1 described by Tomita et al., J. Invest. Dermatol., 85:426-430 (1985), and Jimenez et al., Proc. Natl. Acad. Sci. USA, 85:3830-3834 (1988). The linking antibody was a mixture of anti mouse and anti rat IgG conjugated to biotin, provided by the manufacturer (Dako). The treated cytospin slides were then lightly counterstained with Mayer's hematoxylin and mounted with liquid glycerol gelatin (Dako). A positive control was similarly prepared using a frozen section of human melanoma tissue. A negative control was prepared by replacing the primary antibody with PBS.

The results show tyrosinase expression in both FS-3 and K1735 liposome-treated cells, when detected by either dopa oxidase reaction of by immunohistochemical staining. The percent of cells expressing tyrosinase was approximately 52% of the total cells, by either assay method. The negative control cells were negative for both the oxidase assay and the immunohistochemical staining assay.

When compared to the calcium phosphate method for transfection of nucleic acid into cultured cells, it was observed that efficiency of transfer of a tyrosinase-gene

expression plasmid into cells was about 50 times greater when liposomes were used in comparison to calcium phosphate.

These results demonstrate that liposomes are effective and efficient at delivering nucleic acid expression vectors into cells, and further that the liposomes can deliver expression vector plasmid which are subsequently able to express the encoded gene. Finally, the results demonstrate that the tyrosinase gene can be effectively introduced and expressed in mammalian cells.

c. Delivery and Expression of Beta-Galactosidase Gene in Hair Follicles of Histocultured Skin

The bacterial gene lac-Z encoding beta-galactosidase was delivered to histocultured skin samples in a liposome preparation to demonstrate selective delivery and expression in hair follicles. Plasmid pM-MuLV-SV-Lac-Z contains a mammalian promoter derived from the Moloney murine leukemia virus (M-MuLV) and the SV40 Virus (SV) which controls the expression of the beta-galactosidase gene (Lac-Z) capable of expression of beta-galactosidase in mammalian cells.

Liposomes were prepared as described in Example 3b, except that the phospholipids comprised PC, PE and cholesterol in a ratio of 5:2:3, and the ratio of plasmid DNA to phospholipid was 200 ug DNA per 20 mg total phospholipid.

White-haired mouse skin was histocultured as described in Example 1, except that the liposome composition was maintained in the culture medium for four days. Thereafter, the skin histoculture medium was changed to the same medium lacking liposomes and including the Lac-Z substrate X-gal, and the X-gal-containing medium was maintained under histoculturing conditions for 18 hours to allow any beta-galactosidase present in the histocultured skin sample to convert the X-gal to the typical visible blue dye. Control

liposome delivery was conducted with naked plasmid DNA (pM-MuLV-SV-Lac-Z) using the same amount of DNA as with the liposome-entrapped plasmid composition.

Histocultured skin samples were then sectioned for histochemistry and evaluated using light microscopy at 125X and 250X magnification. The results are shown in Figures 5A-5D. The presence of expressed Lac-Z gene indicated by dark blue spots is only seen in Figures 5A and 5B which received liposome-entrapped plasmid; no dark spots are observed in Figures 5C and 5D. Furthermore, the dark spots are observed in the hair follicles and not significantly observable in the tissues adjacent to the hair follicles.

The results show that the Lac-Z gene was expressed in hair follicles and was not detectable in the other portions of the histocultured skin sample, indicating the selectivity of the liposome delivery method.

4. In Vivo Liposome-Mediated Delivery of Beneficial Compounds to Hair Follicles in Mice

The present methods were used to deliver beneficial compounds to hair follicles in vivo by administration of a liposome composition of the present invention containing either melanin or calcein to mice.

Liposomes were prepared essentially as described in Example 1. Twenty milligram (mg) of PC were rotary evaporated as described, and resuspended by sonication in 0.5 ml of PBS. Thereafter, 0.5 ml of either calcein (10 mg/ml) or melanin (10 mg/ml) solution, respectively, were added to sonicated PC liposome composition, and further sonicated for 6 minutes, followed by freeze-thawing three times. The resulting liposome composition was extruded through a 0.6-1.0 uM filter and separated from the non-entrapped calcein or melanin by gel filtration on a Sepharose 4B column eluted with PBS to form liposome-entrapped beneficial compound composition (calcein or

melanin).

Two to 4 week-old pre-shaved outbred white-haired mice were used for in vivo topical liposome delivery of entrapped beneficial compound to hair follicles. A sample of about 250 microliters of the liposome composition entrapping calcein or melanin was applied directly to the dorsal skin on the mouse in an area of approximately 1.5 cm^2 using a sutured bandaid patch to immobilize the liposome composition onto the skin and to prevent evaporation. The liposome composition was re-applied every 1 hour for 6 hours, with the last application remaining for a total of 24 hours at which time the skin samples were taken by punch biopsy for analysis. For time course experiments, one mouse was used for each time period, with 6 punch biopsies taken from each mouse, at 0.5, 1, 2, 4, 6, 16 and 24 hours. Prior to punch biopsy, the skin was cleaned with an alcohol swab to eliminate any material remaining on the surface of the mouse's skin. For controls, the same amount of calcein or melanin was applied without liposome as with samples containing liposome-entrapped beneficial compound.

After liposome treatment, the skin samples were harvested and cut to very thin (5 mm) pieces of tissue sectioned along the vertical direction of the hair follicles, and subsequently observed by either light or fluorescent microscopy and photographed. For melanin-treated samples, the tissue sample was first counter-stained with BCECF-AM and propidium iodide (PI) for fluorescent microscopy, or prepared for histology and stained in paraffin sections using hematoxylin and eosin for light microscopy. For calcein-treated samples, the tissue sample was first counter-stained with propidium iodide (PI) for fluorescent microscopy.

Skin samples containing calcein were also analyzed by spectrofluorimetry to determine the effective concentration of a delivered beneficial compound into a selected tissue.

To that end, three samples each containing two pieces of a 2-mm punch biopsy of skin for each time point were put into 2 ml of PBS and sonicated in the water bath sonicator for 2 min. The sonicated sample was then centrifuged for 10 minutes in a microcentrifuge at 14,000 x g, and the resulting supernatant was measured by spectrofluorimetry at an excitation wavelength of 496 nm and an emission wavelength of 517 nm for detecting calcein. The concentration of calcein delivered into the skin tissue was determined from the spectrofluorometric readings by comparison to a standard curve.

Figures 6A-6C show the results of delivery of calcein using liposome-entrapped calcein (Figures 6A and 6B) and naked calcein (Figure 6C) after 20 hours. Notice that the liposome-mediated delivery has allowed the calcein to penetrate deep into the hair follicles and shafts, whereas control calcein was trapped in the stratum corneum and did not enter the hair shafts or follicles.

Time course analysis of effectiveness of liposome-entrapped calcein-mediated delivery showed that by 24 hours 22.15 nanograms (ng) per mm^2 of calcein was observed delivered in the hair follicles, whereas only about 1.4 ng/mm^2 of naked calcein was observed delivered after 24 hours, and this amount did not increase with time.

Figures 7A-7C illustrate the results in which melanin has been delivered using liposome-entrapped compound after 24 hours of treatment. Figures 7A and 7B show the melanin delivered into the hair shafts in a pattern that illustrates that the delivered melanin forms the exact pattern of naturally melanized hair shafts. Figure 7C shows the melanin delivered into the hair follicle cells. Therefore, these results demonstrate that topical <u>in vivo</u> administration of liposome resulted in delivery of melanin to both the hair follicle and hair shaft.

Skin samples containing melanin were also analyzed by

spectrophotometry to determine the effective concentration of a delivered beneficial compound into a selected tissue. To that end, three samples each containing two pieces of a 2-mm punch biopsy of skin for each time point were put into 2 ml of PBS and sonicated in the water bath sonicator for 2 min. The sonicated sample was then centrifuged for 10 minutes in a microcentrifuge at 14,000 x g, and the resulting supernatant was measured by spectrophotometry at an absorption wavelength of 300 nm for detecting absorption by melanin. The concentration of melanin delivered into the skin tissue was determined from the spectrophotometric readings by comparison to a standard curve.

Readings from the skin samples in the time course study showed that liposome-entrapped melanin was delivered specifically to the hair follicles after 16 hours to a level of about 19.0 ug/mm^2 whereas less than 2.0 ug/mm^2 of melanin was delivered in the same time period using non-entrapped melanin.

The above results indicate that the liposome-targeted melanin or calcein were selectively delivered to the hair follicle and hair shafts within the follicle, but non-entrapped compound was not delivered to the hair follicle, and instead was restricted to the skin surface, particularly the stratum corneum. Therefore, the liposome-mediated delivery of beneficial compounds is seen to be effective at specific delivery to hair follicles and hair shafts in a living animal, demonstrating <u>in vivo</u> efficacy of the liposome-mediated delivery methods described herein.

As a further control plasma calcein concentrations were also measured by taking blood samples from the lateral tail vein of mice during the course of administration of liposome-entrapped calcein at 0.5, 1, 2, 4, 6, and 24 hours after topical administration. The harvested blood was transferred to a serum separator tube (Vacutainer, Becton Dickinson), and spun at 2000 x g for 10 min to isolate

plasma. Thereafter, calcein was measured by spectrofluorimetry at an excitation wavelength of 496 nm and an emission wavelength of 517 nm for detecting calcein. The concentration of calcein in the plasma was determined from the spectrofluorometric readings by comparison to a standard curve. Over a 24 hour time period, no detectable calcein entered the blood circulation. This is an important observation as it indicates that a beneficial compound, when administered by the present liposome-mediated methods, can be selectively targeted to the hair follicle and hair shaft without entry into the systemic circulation where it may exert undesirable side effects, and that safe follicle/shaft delivery is possible.

Although the present invention has now been described in terms of certain preferred embodiments, and exemplified with respect thereto, one skilled in the art will readily appreciate that various modifications, changes, omissions and substitutions may be made without departing from the spirit thereof.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i) APPLICANT:
(A) NAME: ANTICANCER, INC.
(B) STREET: 7917 Ostrow Street
(C) CITY: San Diego
(D) STATE: CA
(E) COUNTRY: USA
(F) POSTAL CODE (ZIP): 92111
(G) TELEPHONE: 619-654-2555

(ii) TITLE OF INVENTION: METHOD FOR DELIVERING BENEFICIAL COMPOSITIONS TO HAIR FOLLICLES

(iii) NUMBER OF SEQUENCES: 3

(iv) COMPUTER READABLE FORM:
(A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25 (EPO)

(v) CURRENT APPLICATION DATA:
(A) APPLICATION NUMBER: PCT/US 94/
(B) FILING DATE: 01-APR-1994

(vi) PRIOR APPLICATION DATA:
(A) APPLICATION NUMBER: US 08/181,471
(B) FILING DATE: 13-JAN-1994

(vi) PRIOR APPLICATION DATA:
(A) APPLICATION NUMBER: US 08/041,553
(B) FILING DATE: 02-APR-1993

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 2384 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(iii) HYPOTHETICAL: NO

(iv) ANTI-SENSE: NO

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 503..2092

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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AATGGTGAAT AGAGTTTTTC ACTTTAACAT AGGCCTATCC CACTGGTGGG ATACGAGCCA     300

ATTCGAAAGA AAAGTCAGTC ATGTGCTTTT CAGAGGATGA AAGCTTAAGA TAAAGACTAA     360

AAGTGTTTGA TGCTGGAGGT GGGAGTGGTA TTATATAGGT CTCAGCCAAG ACATGTGATA     420

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      60                  65                  70

GAT GAC CGG GAG TCG TGG CCT TCC GTC TTT TAT AAT AGG ACC TGC CAG      772
Asp Asp Arg Glu Ser Trp Pro Ser Val Phe Tyr Asn Arg Thr Cys Gln
  75                  80                  85                  90
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                95                  100                 105

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Phe Trp Gly Pro Asn Cys Thr Glu Arg Arg Leu Leu Val Arg Arg Asn
            110                 115                 120

ATC TTC GAT TTG AGT GCC CCA GAG AAG GAC AAA TTT TTT GCC TAC CTC      916
Ile Phe Asp Leu Ser Ala Pro Glu Lys Asp Lys Phe Phe Ala Tyr Leu
        125                 130                 135

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Thr Leu Ala Lys His Thr Ile Ser Ser Asp Tyr Val Ile Pro Ile Gly
    140                 145                 150

ACC TAT GGC CAA ATG AAA AAT GGA TCA ACA CCC ATG TTT AAC GAC ATC     1012
Thr Tyr Gly Gln Met Lys Asn Gly Ser Thr Pro Met Phe Asn Asp Ile
155                 160                 165                 170

AAT ATT TAT GAC CTC TTT GTC TGG ATG CAT TAT TAT GTG TCA ATG GAT     1060
Asn Ile Tyr Asp Leu Phe Val Trp Met His Tyr Tyr Val Ser Met Asp
                175                 180                 185

GCA CTG CTT GGG GGA TCT GAA ATC TGG AGA GAC ATT GAT TTT GCC CAT     1108
Ala Leu Leu Gly Gly Ser Glu Ile Trp Arg Asp Ile Asp Phe Ala His
            190                 195                 200

GAA GCA CCA GCT TTT CTG CCT TGG CAT AGA CTC TTC TTG TTG CGG TGG     1156
Glu Ala Pro Ala Phe Leu Pro Trp His Arg Leu Phe Leu Leu Arg Trp
        205                 210                 215

GAA CAA GAA ATC CAG AAG CTG ACA GGA GAT GAA AAC TTC ACT ATT CCA     1204
Glu Gln Glu Ile Gln Lys Leu Thr Gly Asp Glu Asn Phe Thr Ile Pro
    220                 225                 230

TAT TGG GAC TGG CGG GAT GCA GAA AAG TGT GAC ATT TGC ACA GAT GAG     1252
Tyr Trp Asp Trp Arg Asp Ala Glu Lys Cys Asp Ile Cys Thr Asp Glu
235                 240                 245                 250

TAC ATG GGA GGT CAG CAC CCC ACA AAT CCT AAC TTA CTC AGC CCA GCA     1300
Tyr Met Gly Gly Gln His Pro Thr Asn Pro Asn Leu Leu Ser Pro Ala
                255                 260                 265

TCA TTC TTC TCC TCT TGG CAG ATT GTC TGT AGC CGA TTG GAG GAG TAC     1348
Ser Phe Phe Ser Ser Trp Gln Ile Val Cys Ser Arg Leu Glu Glu Tyr
            270                 275                 280

AAC AGC CAT CAG TCT TTA TGC AAT GGA ACG CCC GAG GGA CCT TTA CGG     1396
Asn Ser His Gln Ser Leu Cys Asn Gly Thr Pro Glu Gly Pro Leu Arg
        285                 290                 295
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CGT AAT CCT GGA AAC CAT GAC AAA TCC AGA ACC CCA AGG CTC CCC TCT      1444
Arg Asn Pro Gly Asn His Asp Lys Ser Arg Thr Pro Arg Leu Pro Ser
    300                 305                 310

TCA GCT GAT GTA GAA TTT TGC CTG AGT TTG ACC CAA TAT GAA TCT GGT      1492
Ser Ala Asp Val Glu Phe Cys Leu Ser Leu Thr Gln Tyr Glu Ser Gly
315                 320                 325                 330

TCC ATG GAT AAA GCT GCC AAT TTC AGC TTT AGA AAT ACA CTG GAA GGA      1540
Ser Met Asp Lys Ala Ala Asn Phe Ser Phe Arg Asn Thr Leu Glu Gly
                335                 340                 345

TTT GCT AGT CCA CTT ACT GGG ATA GCG GAT GCC TCT CAA AGC AGC ATG      1588
Phe Ala Ser Pro Leu Thr Gly Ile Ala Asp Ala Ser Gln Ser Ser Met
            350                 355                 360

CAC AAT GCC TTG CAC ATC TAT ATG AAT GGA ACA ATG TCC CAG GTA CAG      1636
His Asn Ala Leu His Ile Tyr Met Asn Gly Thr Met Ser Gln Val Gln
        365                 370                 375

GGA TCT GCC AAC GAT CCT ATC TTC CTT CTT CAC CAT GCA TTT GTT GAC      1684
Gly Ser Ala Asn Asp Pro Ile Phe Leu Leu His His Ala Phe Val Asp
    380                 385                 390

AGT ATT TTT GAG CAG TGG CTC CGA AGG CAC CGT CCT CTT CAA GAA GTT      1732
Ser Ile Phe Glu Gln Trp Leu Arg Arg His Arg Pro Leu Gln Glu Val
395                 400                 405                 410

TAT CCA GAA GCC AAT GCA CCC ATT GGA CAT AAC CGG GAA TCC TAC ATG      1780
Tyr Pro Glu Ala Asn Ala Pro Ile Gly His Asn Arg Glu Ser Tyr Met
                415                 420                 425

GTT CCT TTT ATA CCA CTG TAC AGA AAT GGT GAT TTC TTT ATT TCA TCC      1828
Val Pro Phe Ile Pro Leu Tyr Arg Asn Gly Asp Phe Phe Ile Ser Ser
            430                 435                 440

AAA GAT CTG GGC TAT GAC TAT AGC TAT CTA CAA GAT TCA GAC CCA GAC      1876
Lys Asp Leu Gly Tyr Asp Tyr Ser Tyr Leu Gln Asp Ser Asp Pro Asp
        445                 450                 455

TCT TTT CAA GAC TAC ATT AAG TCC TAT TTG GAA CAA GCG AGT CGG ATC      1924
Ser Phe Gln Asp Tyr Ile Lys Ser Tyr Leu Glu Gln Ala Ser Arg Ile
    460                 465                 470

TGG TCA TGG CTC CTT GGG GCG GCG ATG GTA GGG GCC GTC CTC ACT GCC      1972
Trp Ser Trp Leu Leu Gly Ala Ala Met Val Gly Ala Val Leu Thr Ala
475                 480                 485                 490

CTG CTG GCA GGG CTT GTG AGC TTG CTG TGT CGT CAC AAG AGA AAG CAG      2020
Leu Leu Ala Gly Leu Val Ser Leu Leu Cys Arg His Lys Arg Lys Gln
                495                 500                 505
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CTT CCT GAA GAA AAG CAG CCA CTC CTC ATG GAG AAA GAG GAT TAC CAC 2068
Leu Pro Glu Glu Lys Gln Pro Leu Leu Met Glu Lys Glu Asp Tyr His
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AGC TTG TAT CAG AGC CAT TTA TAAAAGGCTT AGGCAATAGA GTAGGGCCAA 2119
Ser Leu Tyr Gln Ser His Leu
525 530

AAAGCCTGAC CTCACTCTAA CTCAAAGTAA TGTCCAGGTT CCCAGAGAAT ATCTGCTGGT 2179

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ACTCAGGTAG AACACACCTG TCTTTGTCTT GCTGTTTTCA CTCAGCCCTT TTAACATTTT 2299

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ATGTGAATTA AAGTGCTCTT ATTTT 2384

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 4646 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(iii) HYPOTHETICAL: NO

(iv) ANTI-SENSE: NO

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 425..4267

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

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     Met Asp Leu Glu Gly Asp Arg Asn Gly Gly Ala Lys Lys Lys Asn
       1               5                  10                  15

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Phe Phe Lys Leu Asn Asn Lys Ser Glu Lys Asp Lys Lys Glu Lys Lys
                  20                  25                  30

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AAG TTG TAT ATG GTG GTG GGA ACT TTG GCT GCC ATC ATC CAT GGG GCT         613
Lys Leu Tyr Met Val Val Gly Thr Leu Ala Ala Ile Ile His Gly Ala
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GGA CTT CCT CTC ATG ATG CTG GTG TTT GGA GAA ATG ACA GAT ATC TTT         661
Gly Leu Pro Leu Met Met Leu Val Phe Gly Glu Met Thr Asp Ile Phe
    65                  70                  75

GCA AAT GCA GGA AAT TTA GAA GAT CTG ATG TCA AAC ATC ACT AAT AGA         709
Ala Asn Ala Gly Asn Leu Glu Asp Leu Met Ser Asn Ile Thr Asn Arg
80                  85                  90                  95

AGT GAT ATC AAT GAT ACA GGG TTC TTC ATG AAT CTG GAG GAA GAC ATG         757
Ser Asp Ile Asn Asp Thr Gly Phe Phe Met Asn Leu Glu Glu Asp Met
                100                 105                 110

ACC AGG TAT GCC TAT TAT TAC AGT GGA ATT GGT GCT GGG GTG CTG GTT         805
Thr Arg Tyr Ala Tyr Tyr Tyr Ser Gly Ile Gly Ala Gly Val Leu Val
            115                 120                 125

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Ala Ala Tyr Ile Gln Val Ser Phe Trp Cys Leu Ala Ala Gly Arg Gln
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160                 165                 170                 175

ACA GAT GAT GTC TCT AAG ATT AAT GAA GTT ATT GGT GAC AAA ATT GGA         997
Thr Asp Asp Val Ser Lys Ile Asn Glu Val Ile Gly Asp Lys Ile Gly
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195 200 205

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210 215 220

GTT CTT GGA CTG TCA GCT GCT GTC TGG GCA AAG ATA CTA TCT TCA TTT 1141
Val Leu Gly Leu Ser Ala Ala Val Trp Ala Lys Ile Leu Ser Ser Phe
225 230 235

ACT GAT AAA GAA CTC TTA GCG TAT GCA AAA GCT GGA GCA GTA GCT GAA 1189
Thr Asp Lys Glu Leu Leu Ala Tyr Ala Lys Ala Gly Ala Val Ala Glu
240 245 250 255

GAG GTC TTG GCA GCA ATT AGA ACT GTG ATT GCA TTT GGA GGA CAA AAG 1237
Glu Val Leu Ala Ala Ile Arg Thr Val Ile Ala Phe Gly Gly Gln Lys
260 265 270

AAA GAA CTT GAA AGG TAC AAC AAA AAT TTA GAA GAA GCT AAA AGA ATT 1285
Lys Glu Leu Glu Arg Tyr Asn Lys Asn Leu Glu Glu Ala Lys Arg Ile
275 280 285

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290 295 300

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305 310 315

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340 345 350

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355 360 365

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370 375 380

AAA CCA GAT AAT ATT AAG GGA AAT TTG GAA TTC AGA AAT GTT CAC TTC 1621
Lys Pro Asp Asn Ile Lys Gly Asn Leu Glu Phe Arg Asn Val His Phe
385 390 395

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AGT TAC CCA TCT CGA AAA GAA GTT AAG ATC TTG AAG GGC CTG AAC CTG      1669
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400                 405                 410                 415

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Lys Val Gln Ser Gly Gln Thr Val Ala Leu Val Gly Asn Ser Gly Cys
                420                 425                 430

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Gly Lys Ser Thr Thr Val Gln Leu Met Gln Arg Leu Tyr Asp Pro Thr
            435                 440                 445

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Glu Gly Met Val Ser Val Asp Gly Gln Asp Ile Arg Thr Ile Asn Val
        450                 455                 460

AGG TTT CTA CGG GAA ATC ATT GGT GTG GTG AGT CAG GAA CCT GTA TTG      1861
Arg Phe Leu Arg Glu Ile Ile Gly Val Val Ser Gln Glu Pro Val Leu
    465                 470                 475

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Phe Ala Thr Thr Ile Ala Glu Asn Ile Arg Tyr Gly Arg Glu Asn Val
480                 485                 490                 495

ACC ATG GAT GAG ATT GAG AAA GCT GTC AAG GAA GCC AAT GCC TAT GAC      1957
Thr Met Asp Glu Ile Glu Lys Ala Val Lys Glu Ala Asn Ala Tyr Asp
                500                 505                 510

TTT ATC ATG AAA CTG CCT CAT AAA TTT GAC ACC CTG GTT GGA GAG AGA      2005
Phe Ile Met Lys Leu Pro His Lys Phe Asp Thr Leu Val Gly Glu Arg
            515                 520                 525

GGG GCC CAG TTG AGT GGT GGG CAG AAG CAG AGG ATC GCC ATT GCA CGT      2053
Gly Ala Gln Leu Ser Gly Gly Gln Lys Gln Arg Ile Ala Ile Ala Arg
        530                 535                 540

GCC CTG GTT CGC AAC CCC AAG ATC CTC CTG CTG GAT GAG GCC ACG TCA      2101
Ala Leu Val Arg Asn Pro Lys Ile Leu Leu Leu Asp Glu Ala Thr Ser
    545                 550                 555

GCC TTG GAC ACA GAA AGC GAA GCA GTG GTT CAG GTG GCT CTG GAT AAG      2149
Ala Leu Asp Thr Glu Ser Glu Ala Val Val Gln Val Ala Leu Asp Lys
560                 565                 570                 575

GCC AGA AAA GGT CGG ACC ACC ATT GTG ATA GCT CAT CGT TTG TCT ACA      2197
Ala Arg Lys Gly Arg Thr Thr Ile Val Ile Ala His Arg Leu Ser Thr
                580                 585                 590

GTT CGT AAT GCT GAC GTC ATC GCT GGT TTC GAT GAT GGA GTC ATT GTG      2245
Val Arg Asn Ala Asp Val Ile Ala Gly Phe Asp Asp Gly Val Ile Val
            595                 600                 605
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GAG AAA GGA AAT CAT GAT GAA CTC ATG AAA GAG AAA GGC ATT TAC TTC 2293
Glu Lys Gly Asn His Asp Glu Leu Met Lys Glu Lys Gly Ile Tyr Phe
610 615 620

AAA CTT GTC ACA ATG CAG ACA GCA GGA AAT GAA GTT GAA TTA GAA AAT 2341
Lys Leu Val Thr Met Gln Thr Ala Gly Asn Glu Val Glu Leu Glu Asn
625 630 635

GCA GCT GAT GAA TCC AAA AGT GAA ATT GAT GCC TTG GAA ATG TCT TCA 2389
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660 665 670

GTC CGT GGA TCA CAA GCC CAA GAC AGA AAG CTT AGT ACC AAA GAG GCT 2485
Val Arg Gly Ser Gln Ala Gln Asp Arg Lys Leu Ser Thr Lys Glu Ala
675 680 685

CTG GAT GAA AGT ATA CCT CCA GTT TCC TTT TGG AGG ATT ATG AAG CTA 2533
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AGT AAC TTG TTT TCA CTA TTG TTT CTA GCC CTT GGA ATT ATT TCT TTT 2725
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CTC ACC AAG CGG CTC CGA TAC ATG GTT TTC CGA TCC ATG CTC AGA CAG 2821
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785 790 795

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GAC CCC TTG GCA GGG AAA GTG CTG CTT GAT GGC AAA GAA ATA AAG CGA 3733
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1090 1095 1100

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1140 1145 1150

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His Arg Leu Ser Thr Ile Gln Asn Ala Asp Leu Ile Val Val Phe Gln
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Gln
1280

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AGACATCATC AAGTGGAGAG AAATCATAGT TTAAACTGCA TTATAAATTT TATAACAGAA 4494

TTAAAGTAGA TTTTAAAAGA TAAAATGTGT AATTTTGTTT ATATTTTCCC ATTTGGACTG 4554

TAACTGACTG CCTTGCTAAA AGATTATAGA AGTAGCAAAA AGTATTGAAA TGTTTGCATA 4614

AAGTGTCTAT AATAAAACTA AACTTTCATG TG 4646

(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 867 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(iii) HYPOTHETICAL: NO

(iv) ANTI-SENSE: NO

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 35..517

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

```
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Ala Val Val Ser His Phe Asn Asp Cys Pro Asp Ser His Thr Gln Phe
    40                  45                  50

TGC TTC CAT GCA ACC TGC AGG TTT TTG GTG CAC GAG GAC AAG CCA GCA        244
Cys Phe His Ala Thr Cys Arg Phe Leu Val His Glu Asp Lys Pro Ala
55                  60                  65                  70

TGT GTC TGC CAT TCT GGG TAC GTT GGT GCA CGC TGT GAG CAT GCG GAC        292
Cys Val Cys His Ser Gly Tyr Val Gly Ala Arg Cys Glu His Ala Asp
                75                  80                  85

CTC CTG GCC GTG GTG GCT GCC AGC CAG AAG AAG CAG GCC ATC ACC GCC        340
Leu Leu Ala Val Val Ala Ala Ser Gln Lys Lys Gln Ala Ile Thr Ala
            90                  95                  100

TTG GTG GTG GTC TCC ATC GTG GCC CTG GCT GTC CTT ATC ATC ACA TGT        388
Leu Val Val Val Ser Ile Val Ala Leu Ala Val Leu Ile Ile Thr Cys
        105                 110                 115

GTG CTG ATA CAC TGC TGC CAG GTC CGA AAA CAC TGT GAG TGG TGC CGG        436
Val Leu Ile His Cys Cys Gln Val Arg Lys His Cys Glu Trp Cys Arg
    120                 125                 130

GCC CTC ATC TGC CGG CAC GAG AAG CCC AGC GCC CTC CTG AAG GGA AGA        484
Ala Leu Ile Cys Arg His Glu Lys Pro Ser Ala Leu Leu Lys Gly Arg
135                 140                 145                 150

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Thr Ala Cys Cys His Ser Glu Thr Leu Val
                155                 160

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GAGATGCCTG GGTGTGCCAC AGACCTTCCT ACTTGGCCTG TAATCACCTG TGCAGCCTTT      654

TGTGGGCCTT CAAAACTCTG TCAAGAACTC CGTCGGCTTG GGGTTATTCA GTGTGACCTA      714

GAGAAGAAAT CAGCGGACCA CGATTTCAAG ACTTGTTAAA AAAGAACTGC AAAGAGACGG      774
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ACTCCTGTTC ACCTAGGTGA GGTGTGTGCA GCAGTTGGTG TCTGAGTCCA CATGTGTGCA 834

GTTGTCTTCT GCCAGCCATG GATTCCAGGC CGT 867

WHAT IS CLAIMED IS:

1. A liposome composition comprising a liposome containing an effective amount of a beneficial compound,

said liposome capable of selectively delivering said beneficial compound to hair follicles,

and said beneficial compound being a lipophobic molecule or a lipophillic molecule having undesirable effects on cells external to said hair follicles.

2. The liposome composition of claim 1 wherein said beneficial compound comprises melanin, and variants thereof.

3. The liposome composition of claim 1 wherein said beneficial compound comprises hair dye.

4. The liposome composition of claim 1 wherein said beneficial compound comprises tyrosinase.

5. The liposome composition of claim 1 wherein said beneficial compound comprises a nucleic acid capable of expressing human tyrosinase.

6. The liposome composition of claim 5 wherein said nucleic acid encodes human tyrosinase including the amino acid residue sequence characteristics of the tyrosinase protein sequence shown in SEQ ID NO 1.

7. The liposome composition of claim 5 wherein said nucleic acid is capable of expressing human p-glycoprotein.

8. The liposome composition of claim 7 wherein said nucleic acid defines the human MDR-1 gene and is capable of expressing p-glycoprotein having the amino acid residue sequence characteristics of the p-glycoprotein sequence shown in SEQ ID NO 2.

9. The liposome composition of claim 5 wherein said liposome composition contains about 100 microgram of said nucleic acid per 0.2 to 1.2 micromoles of phospholipid.

10. The liposome composition of claim 1 wherein said liposome composition comprises pH-sensitive liposomes.

11. The liposome composition of claim 10 wherein said pH-sensitive liposomes are comprised of PE and OE in a molar

ratio of 7:3.

12. The liposome composition of claim 1 wherein said liposome composition comprises a first phospholipid selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol.

13. The liposome composition of claim 12 wherein said liposome composition comprises PC:PE:cholesterol in a ratio of 5:2:3.

14. The liposome composition of claim 12 wherein said liposome composition further comprises a cationic phospholipid selected from the group consisting of D282, D378, D383, D3886, D3897 and D3899.

15. The liposome composition of claim 14 wherein said liposome composition contains a molar ratio of said first phospholipid to said cationic phospholipid of 0.8:1.0-1.2.

16. A method for restoring hair color to the hair of a mammal, comprising applying a therapeutically effective amount of a liposome composition to a skin area on said mammal having a plurality of hair follicles,

said liposome composition comprising a liposome containing an effective amount of at least one selected hair color-restoring agent,

and said liposome capable of selectively delivering said hair color-restoring agent to said hair follicles.

17. The method of claim 16 wherein said applying is conducted repeatedly at defined intervals to provide prolonged hair color restoration.

18. The method of claim 16 wherein said hair color-restoring agent comprises melanin, and variants thereof.

19. The method of claim 16 wherein said hair color-restoring agent comprises hair dye.

20. The method of claim 16 wherein said hair color-restoring agent comprises tyrosinase.

21. The method of claim 16 wherein said hair color-

restoring agent comprises a nucleic acid capable of expressing human tyrosinase in a cell of said hair follicles.

22. The method of claim 21 wherein said nucleic acid encodes human tyrosinase including the amino acid residue sequence characteristics of the tyrosinase protein sequence shown in SEQ ID NO 1.

23. The method of claim 21 wherein said liposome composition contains about 100 microgram of said nucleic acid per 0.2 to 1.2 micromoles of phospholipid.

24. The method of claim 16 wherein said liposome composition comprises pH-sensitive liposomes.

25. The method of claim 24 wherein said pH-sensitive liposomes are comprised of PE and OE in a molar ratio of 7:3.

26. The method of claim 16 wherein said liposome composition comprises a first phospholipid selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol.

27. The method of claim 26 wherein said liposome composition comprises PC:PE:cholesterol in a ratio of 5:2:3.

28. The method of claim 26 wherein said liposome composition further comprises a cationic phospholipid selected from the group consisting of D282, D378, D383, D3886, D3897 and D3899.

29. The method of claim 28 wherein said liposome composition contains a molar ratio of said first phospholipid to said cationic phospholipid of 0.8:1.0-1.2.

30. A method of directly and selectively delivering a beneficial compound to hair follicles of a mammal comprising the step of applying a liposome composition topically to skin areas of a mammal having a plurality of hair follicles, said liposome composition comprising a liposome containing an effective amount of at least one selected

beneficial compound,

said liposome capable of selectively delivering said beneficial compound to said hair follicles,

and said beneficial compound being a lipophobic molecule or a lipophillic molecule having undesirable effects on cells external to said hair follicles,

whereby said beneficial compound is preferentially transmitted to said hair follicles and enters into said hair follicles.

31. The method of claim 30 wherein said compound comprises melanin, and variants thereof.

32. The method of claim 30 wherein said compound comprises hair dye.

33. The method of claim 30 wherein said compound comprises protein.

34. The method of claim 33 wherein said protein is tyrosinase.

35. The method of claim 33 wherein said protein is p-glycoprotein.

36. The method of claim 33 wherein said protein is human tumor growth factor-alpha.

37. The method of claim 30 wherein said compound comprises nucleic acid.

38. The method of claim 37 wherein said nucleic acid is capable of expressing an effective amount of a replacement therapy protein.

39. The method of claim 38 wherein said expressed protein is tyrosinase.

40. The method of claim 39 wherein said protein has the amino acid residue sequence characteristics of the sequence shown in SEQ ID NO 1.

41. The method of claim 38 wherein said expressed protein is p-glycoprotein expressed by the human gene MDR-1.

42. The method of claim 41 wherein said protein has the amino acid residue sequence characteristics of the

sequence shown in SEQ ID NO 2.

43. The method of claim 37 wherein said liposome composition contains about 100 microgram of said nucleic acid per 0.2 to 1.2 micromoles of phospholipid.

44. The method of claim 37 wherein said nucleic acid comprises a hair growth stimulating gene.

45. The method of claim 30 wherein said skin containing hair follicles is present on a mammal, and said delivery occurs in vivo.

46. The method of claim 45 wherein said mammal is a human.

47. The method of claim 30 wherein said liposome composition comprises pH-sensitive liposomes.

48. The method of claim 47 wherein said pH-sensitive liposomes are comprised of PE and OE in a molar ratio of 7:3.

49. The method of claim 30 wherein said liposome composition comprises a first phospholipid selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol.

50. The method of claim 49 wherein said liposome composition comprises PC:PE:cholesterol in a ratio of 5:2:3.

51. The method of claim 49 wherein said liposome composition further comprises a cationic phospholipid selected from the group consisting of D282, D378, D383, D3886, D3897 and D3899.

52. The method of claim 51 wherein said liposome composition contains a molar ratio of said first phospholipid to said cationic phospholipid of 0.8:1.0-1.2.

53. The method of claim 30 wherein said nucleic acid encodes an antisense molecule.

54. A method for inhibiting chemotherapy-induced alopecia in a mammal, comprising applying a therapeutically effective amount of a liposome composition to a skin area on

said mammal having a plurality of hair follicles,

said liposome composition comprising a liposome containing an effective amount of a nucleic acid capable of expressing in cells of said hair follicles a protein that confers chemoresistance to said hair follicles,

said liposome capable of selectively delivering said nucleic acid to said hair follicles.

55. The method of claim 54 wherein said applying is conducted repeatedly at defined intervals to provide prolonged chemoresistance.

56. The method of claim 54 wherein said nucleic acid is capable of expressing human p-glycoprotein in a cell of said hair follicles.

57. The method of claim 54 wherein said nucleic acid defines the human MDR-1 gene and is capable of expressing p-glycoprotein having the amino acid residue sequence characteristics of the p-glycoprotein sequence shown in SEQ ID NO 2.

58. The method of claim 54 wherein said liposome composition contains about 100 microgram of said nucleic acid per 0.2 to 1.2 micromoles of phospholipid.

59. The method of claim 54 wherein said liposome composition comprises pH-sensitive liposomes.

60. The method of claim 59 wherein said pH-sensitive liposomes are comprised of PE and OE in a molar ratio of 7:3.

61. The method of claim 54 wherein said liposome composition comprises a first phospholipid selected from the group consisting of PC, EPC, DOPC, DPPC, PE, DOPE and cholesterol.

62. The method of claim 61 wherein said liposome composition comprises PC:PE:cholesterol in a ratio of 5:2:3.

63. The method of claim 61 wherein said liposome composition further comprises a cationic phospholipid selected from the group consisting of D282, D378, D383,

D3886, D3897 and D3899.

64. The method of claim 63 wherein said liposome composition contains a molar ratio of said first phospholipid to said cationic phospholipid of 0.8:1.0-1.2.

5

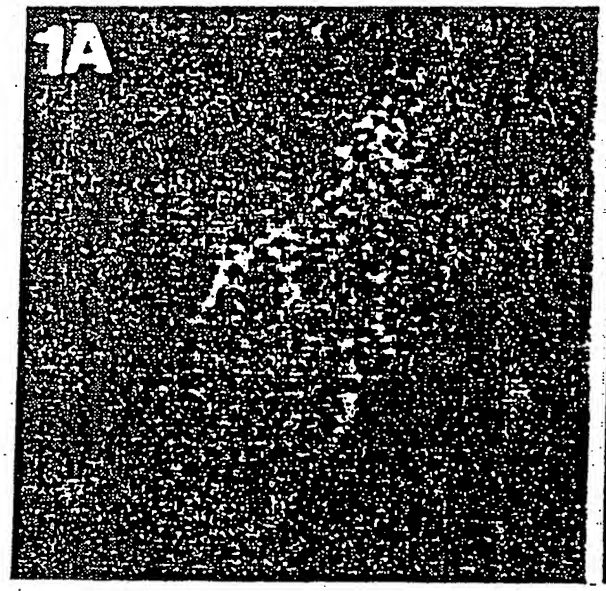
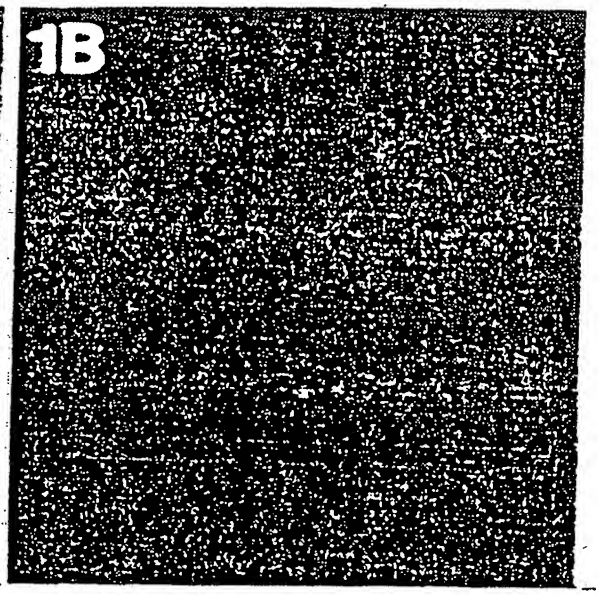


FIGURE 1A



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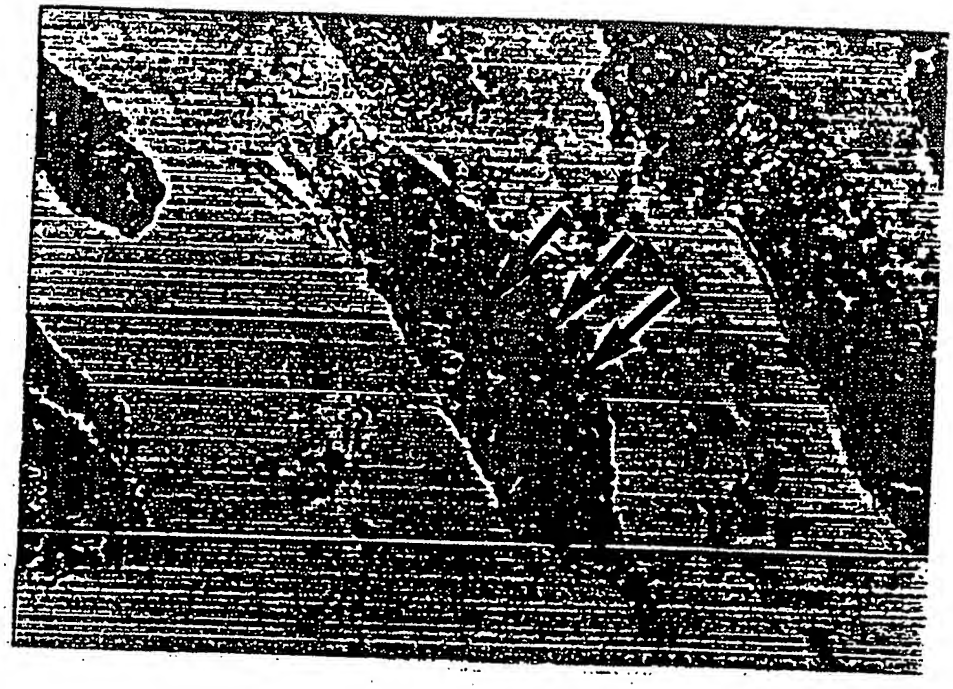


FIGURE 2

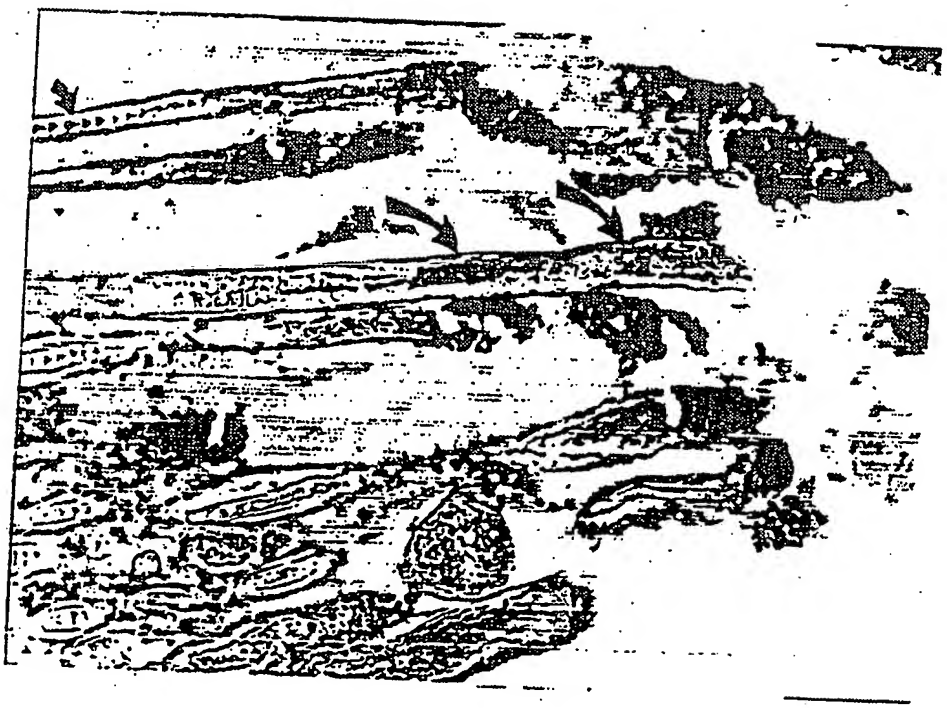


FIGURE 3

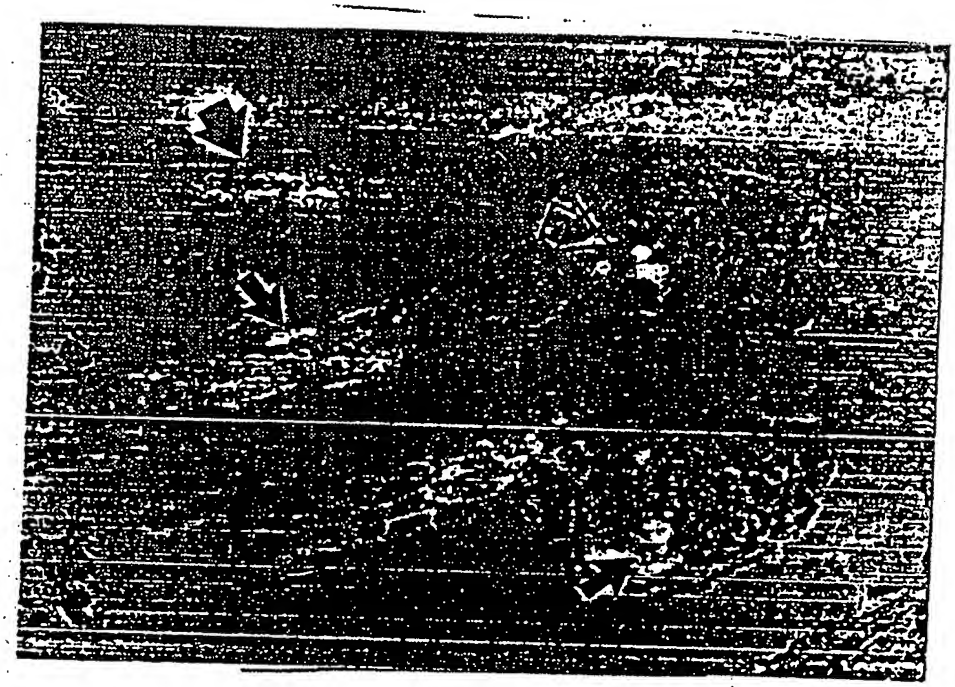


FIGURE 4

WO 94/22468 PCT/US94/03634

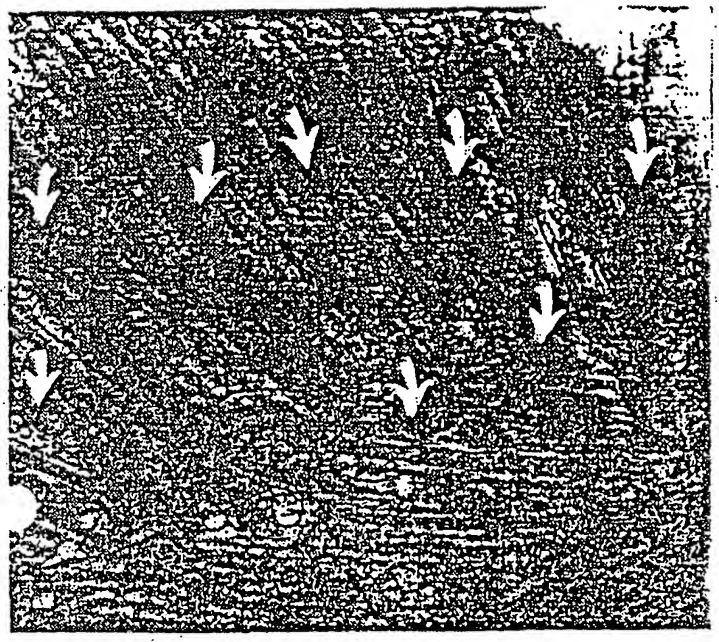


FIGURE 5A

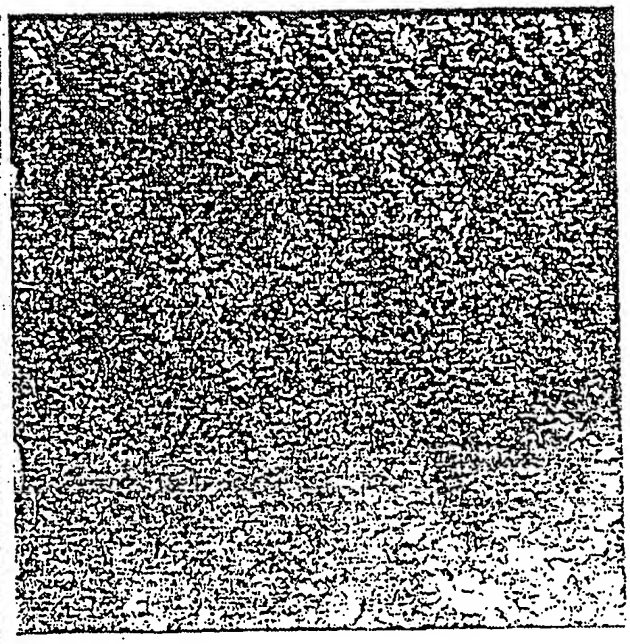


FIGURE 5C

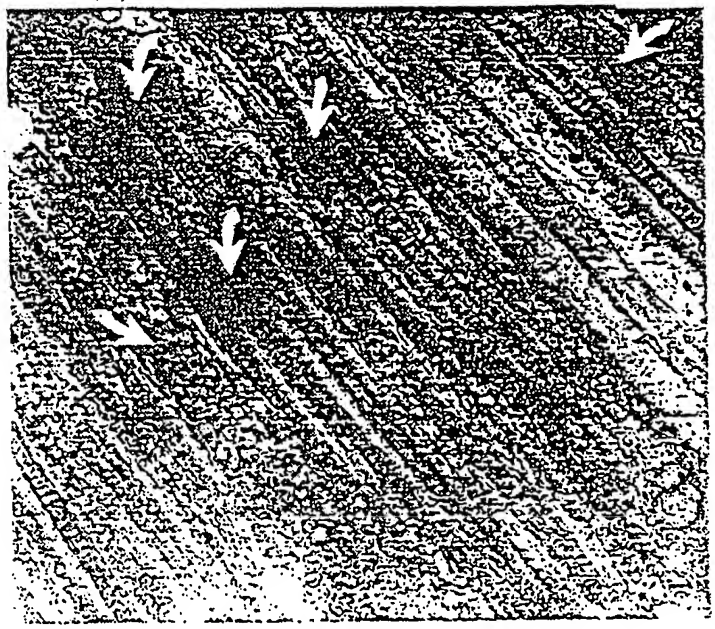


FIGURE 5B

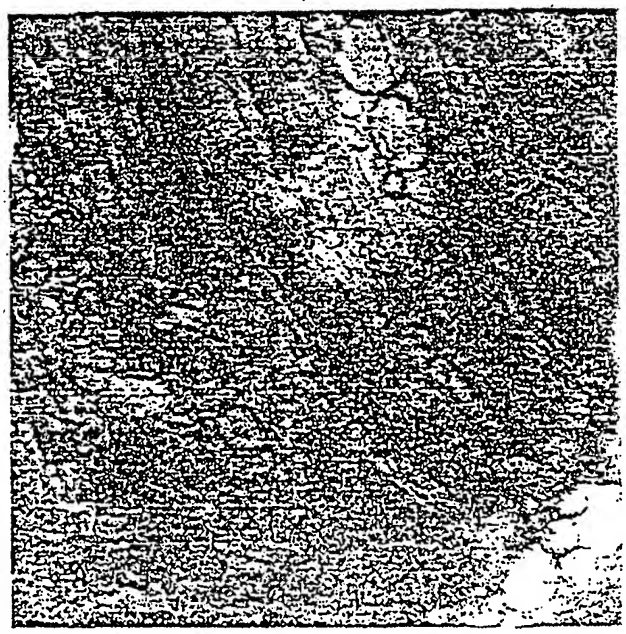


FIGURE 5D

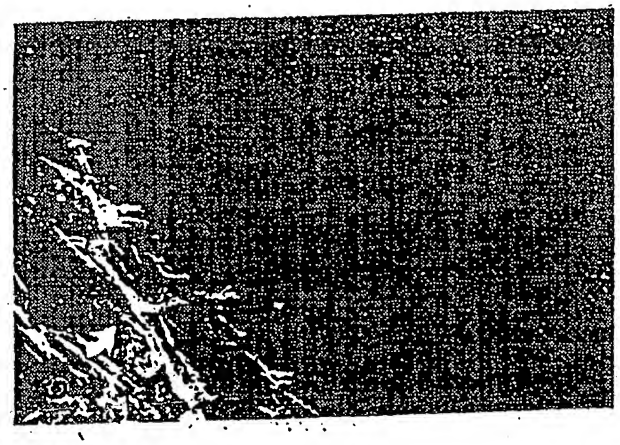


FIGURE 6C

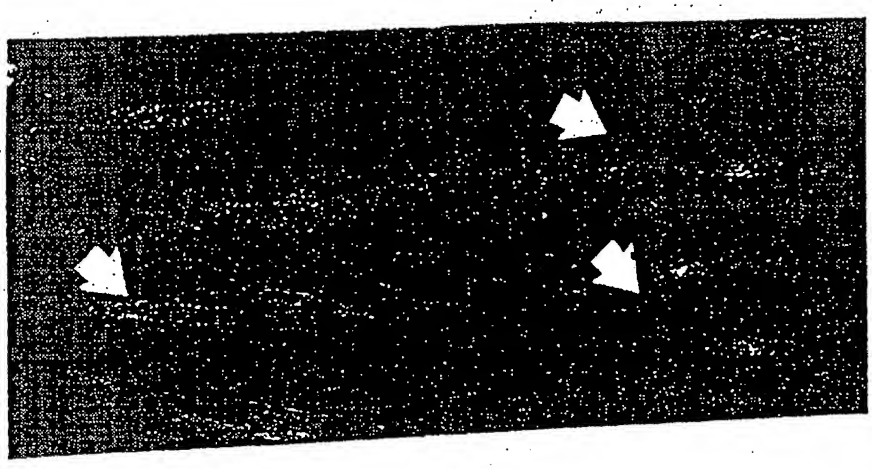


FIGURE 6B

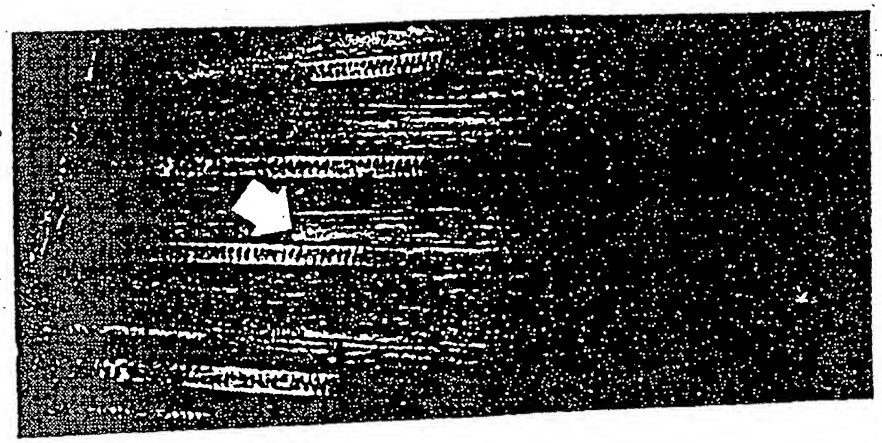


FIGURE 6A

FIGURE 7A

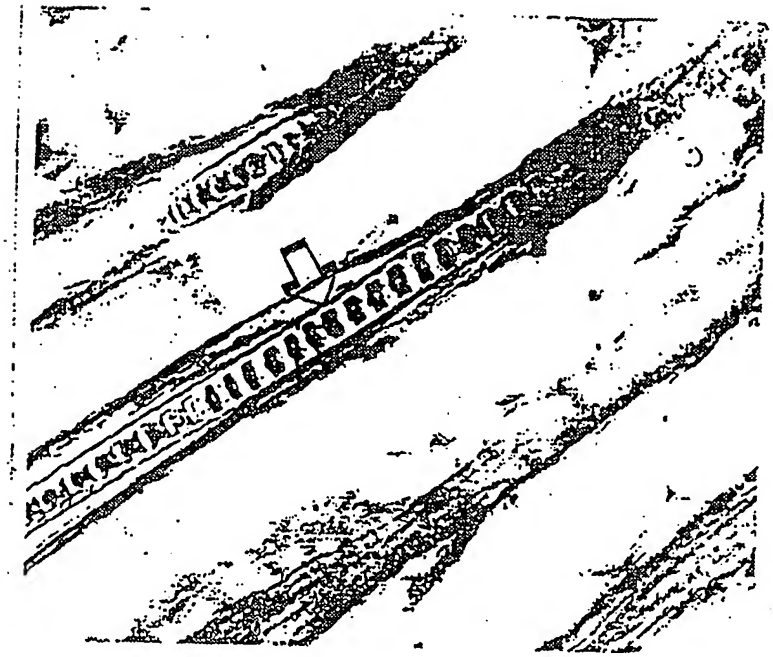


FIGURE 7B

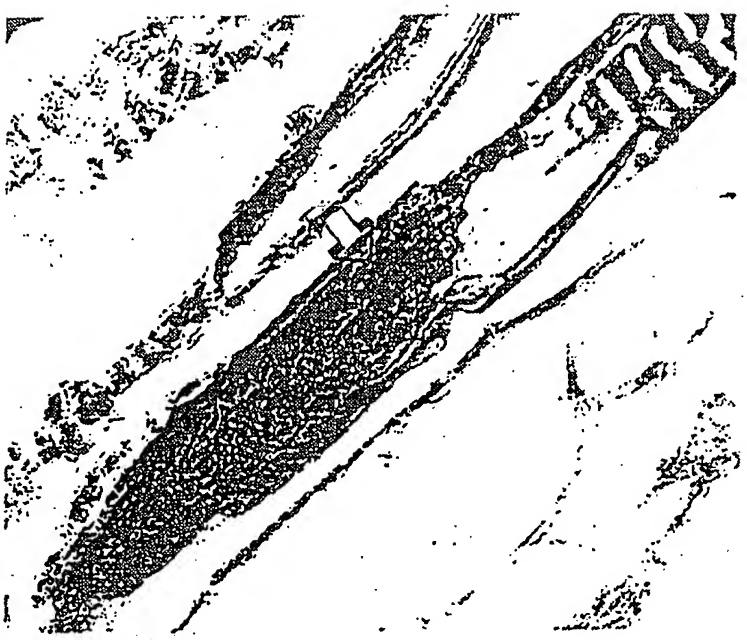
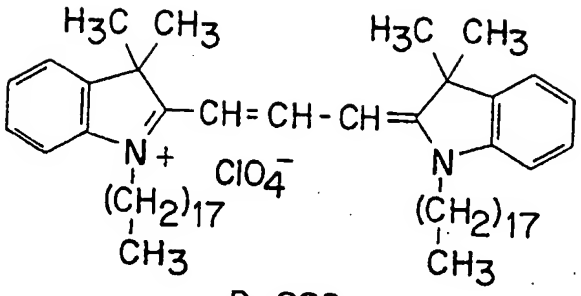
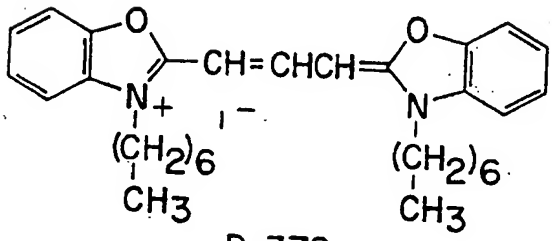


FIGURE 7C



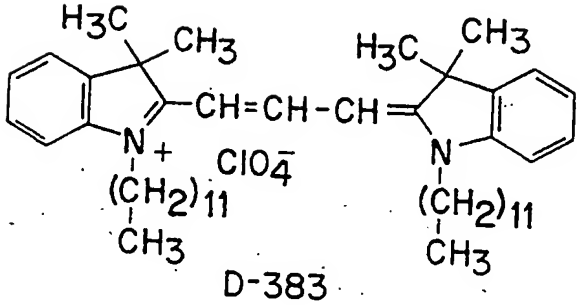
D-282

FIG. 8A



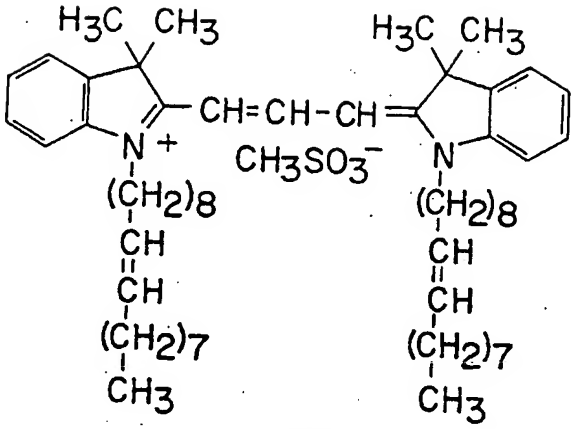
D-378

FIG. 8B



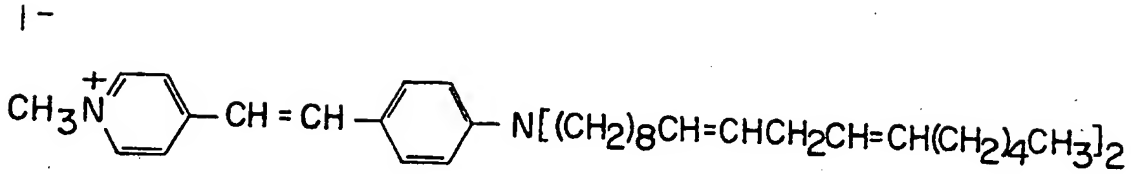
D-383

FIG. 8C



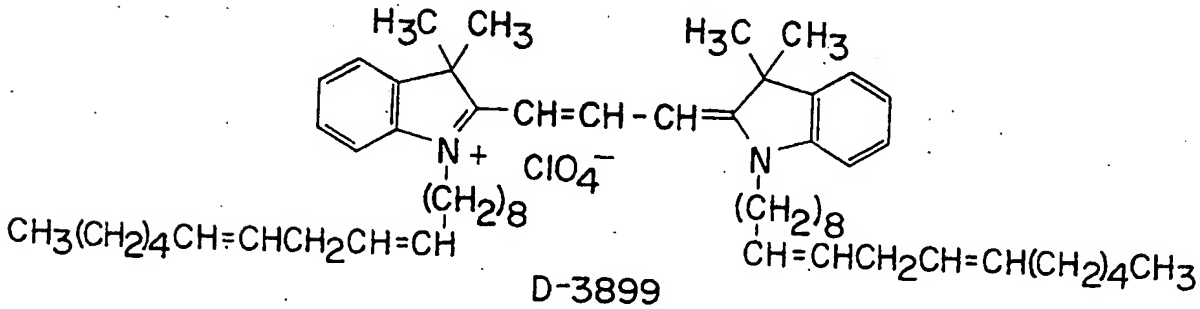
D-3886

FIG. 8D



D-3897

FIG. 8E



D-3899

FIG. 8F

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/03634

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61K 37/22
US CL :424/450

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/450

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS; DIALOG DATABASES: BIOSIS PREVIEWS, MEDLINE, WORLD PATENT INDEX, CA SEARCH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	In Vitro Cellular & Developmental Biology, Volume 29A, Number 3, Part I, issued March 1993, Li et al., "Liposomes Can Specifically Target Entrapped Melanin to Hair Follicles in Histocultured Skin," pages 192-194, see entire article.	1, 2, 10-18, 30, 31, 45-52

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 JUNE 1994	JUL 07 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer JOHNNY F. RAILEY II, PH.D. Telephone No. (703) 308-0196

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/03634

Box I Observations where certain claims were found unsearchable (Continuation f item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1, 2. 10-18, 30, 31, 45-52

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

I. Claims 1, 2, 10-18, 30, 31 and 45-52, drawn to a first product, a first distinct composition of liposomes comprising melanin and first method of use for restoration of hair color or delivery of a beneficial compound, either of which involves delivery of a distinct liposome composition comprising melanin, classified in class 424, subclass 450.

II. Claim 3, drawn to a second distinct composition of liposomes comprising hair dye, classified in class 424, subclass 420.

III. Claim 4, drawn to a third distinct composition of liposomes comprising tyrosinase, classified in class 424, subclass 420.

IV. Claims 5, 6 and 9, drawn to a fourth distinct composition of liposomes comprising nucleic acid expressing tyrosinase, classified in class 424, subclass 420.

V. Claims 7 and 8, drawn to a fifth distinct composition of liposomes comprising nucleic acid expressing p-glycoprotein, classified in class 424, subclass 420.VI. Claims 19, 24-29 and 32 drawn to a second method for restoration of hair colorordelivery of a beneficial compound, either of which involves delivery of a distinct liposome composition comprising hair dye, classified in class 424, subclass 420.

VII. Claims 20, 33 and 34 drawn to a third method for restoration of hair color or delivery of a beneficial compound, either of which involves delivery of a distinct liposomecomposition comprising tyrosinase, classified in class 424, subclass 420.

VIII. Claims 21-23, 37-40, 43 and 44, drawn to a fourth method for restoration of hair color or delivery of a beneficial compound,either of which involves delivery of a distinct liposome composition comprising nucleic acid expressing tyrosinase, classified in class 424, subclass 420.

IX. Claim 35, drawn to a fifth method for delivery of a beneficial compound, which involves delivery of a distinct liposome composition comprising p-glycoprotein, classified in class 424, subclass 420.
X. Claim 36, drawn to a sixth method for delivery of a beneficial compound, which involves delivery of adistinctliposome composition comprising human tumor growth factor-alpha, classified in class 424, subclass 420.XI. Claims 41, 42 and 54-63, drawn to a seventh method for delivery of a beneficial compound or inhibiting chemotherapy-induced alopecia, which involves delivery of a distinct liposome composition comprising nucleic acid expressing human MDR-1 gene (or human p-glycoprotein)classified in class 424, subclass 420.

XII. Claim 53, drawn to an eighth method for delivery of a beneficial compound, which involves delivery of a distinct liposome composition comprising an antisense molecule, classified in class 424, subclass 420.